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ED-CR-76102

CONTINUED DEVELOPMENT OF PATTERN RECOGNITION TECHNIQUES

Final Report

by

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J. J. O'Connor

January 1977

ORGANON DIAGNOSTICS
9060 East Flair Drive
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Contract No. DAAA 15-74-C-0239

DEPARTMENT OF THE ARMY
Headquarters, Edgewood Arsenal
Aberdeen Proving Ground, Maryland 21010

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This program involved the continued development of pattern recognition equipment used in conjunction with the PACT system. The existing pattern recognition electronics were improved in order that mold spores would be rejected while retaining an acceptable sensitivity to egg challenges. Two mold spore detectors were fabricated accordingly. Two identical alarm logic systems were also designed and fabricated. The alarm logic systems perform complex processing of pattern recognition outputs automatically and continually. The system will alert the operator of the likelihood of an aerosol

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challenge. Prior to the development of the mold spore detector and alarm logic systems, a data acquisition was completed involving the FM tape recording of simulants and backgrounds. A subsequent data analysis was performed consisting of the analysis of selected portions of the acquired data which provided analytical tools for the development of the aforementioned hardware.

PREFACE

The research and development covered by this final report was authorized under Job 1123 of the Organon Diagnostics Engineering Department. The work was conducted during the period from June 7, 1974 to May 31, 1976.

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Mr. Gene Paulsen, Design Engineer, designed and fabricated all of the electronic hardware of this program. He also performed data acquisition and test trials at Edgewood Arsenal. E. Boyer, Associate Engineer, conducted *simulated tests on the hardware in the laboratory.*

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1.0 INTRODUCTION

The purpose of this program has been the continued development of pattern recognition methods applied to the PACT system. Under a previous contract (DAAA 15-72-C-0375) pattern recognition instrumentation was designed, fabricated and installed in conjunction with the Mark VI PACT detector system. The present program has involved further analysis, refinement of existing pattern recognition hardware, and the design, fabrication, and installation of two additional subsystems.

By way of background, the function of this PACT optical system is to sample the ambient air continuously by depositing airborne particles onto a clear plastic tape and subjecting these particles to a highly specific protein stain and subsequently scanning them with a microscopic flying spot comparable in size to individual bacteria, etc., which are to be observed. The flying spot is viewed by two photomultiplier tubes (PMTs), one through a red filter and one through a green filter. By observing the relative amplitudes of these two video channels, distinction between stained organisms and opaque particles is made by the electronics. An opaque particle is of no interest, while a stained particle suggests the presence of bacteria. This system is highly sensitive, as the presence of a single organism can be detected in a clean laboratory environment. However, in sampling a natural outside-air environment, a variety of other organic material which is of no interest also is stained. The presence of this extraneous material serves to raise the required-detection-threshold level in order to reduce false alarms. This higher threshold level, in turn, reduces the sensitivity of the device, since it requires greater challenge concentrations to produce an alarm.

Prior to the development of the pattern recognition electronics under the previous contract, it had been found that attempts to reduce the interference due to nonbacterial material was usually successful. Although the adoption of these techniques brought the detection level down to a concentration of interest to the Army, the false alarm rate remained in excess of an acceptable figure, indicating the need for further refinement of the system. Subsequently, two significant developments occurred:

- The determination that man-made aerosols leave unique, recognizable patterns when impacted upon the tape of the PACT system.
- The availability of a vast selection of low-cost integrated circuits makes feasible the fabrication of highly sophisticated and complex signal-processing electronics such as pattern recognition systems at a reasonable cost and compact size.

In addition, various analytical techniques have been applied to such related problems as the scanning of photographs for specific information, reading printed characters, enhancing images, and improving signal extraction from noise in communications.

As a consequence, under the previous contract, three electronic subsystems were developed which sort the video signals from the PACT microscope on the basis of green-to-red amplitude ratio, pulse height and width and grouping characteristics of the organisms scanned by the microscope. Substantial improvements in the performance of the PACT system in its ability to screen challenge material out of the ambient background were observed after installing these electronic subsystems. Also, a better understanding of the statistical nature of challenges and backgrounds was obtained as a result of the data acquisition and analysis phase of that program.

The consequent development of the PACT together with increased understanding of the statistics of challenges and backgrounds afforded a vantage point for planning further development and improvement. Specific areas chosen for continued development were the following:

- Obtain new tape recordings of video signals and backgrounds to provide a library of high quality FM recordings.
- Analyze statistical data taken from these recordings to faciliate optimization of parameters in the previously developed pattern recognition system.
- Design and fabricate an alarm logic system to be incorporated with the remainder of the electronics.
- Refine current pattern recognition electronics to detect egg or reject mold spores since it has been desirable to be able to distinguish the often present spurious mold spore from egg challenges which it resembles.
- Fabricate spare electronic hardware.

It is these five areas, therefore, that the tasks of the present contract have been directed.

2.0 SUMMARY

As discussed in the introduction, the primary purpose of this program has been the continued development of pattern recognition equipment used in conjunction with the PACT system. The principal goals of the program have been to refine the existing pattern recognition electronics and to develop and incorporate additional electronic subsystems into this existing equipment. Specifically this has entailed PACT video data acquisition and analysis, the modification of the existing correlator circuit, the development and fabrication of an alarm logic system and the development of a mold spore detector for rejecting mold spores which are scanned by the PACT microscope.

The specific tasks of this program were grouped into four main task areas:

- Optimization of alarm and false alarm sensitivity.
- Develop and build an alarm logic system.
- Refine the existing pattern recognition electronics to detect or reject mold spores.
- Fabricate spare electronic hardware.

The first task was primarily a data acquisition and analysis task with hardware modification being one final output. The next two tasks involved the design fabrication and installation of new hardware. Finally, evaluative tests of the modified, previously developed hardware and of the new hardware were conducted.

The first task, whose primary purpose was the optimization of alarm and false alarm sensitivity consisted of two primary subtasks:

- Data acquisition.
- Data analysis.

The data acquisition involved the tape recording of simulants and backgrounds, and the data analysis consisted primarily of analyzing selected portions of the tape recordings which provided analytical tools for hardware development and refinement.

The data acquisition was carried out in three recording sessions in June, July and August 1974. The first and last sessions were conducted at the Dugway Proving Grounds at Dugway, Utah. The second session was held at Edgewood Arsenal, Maryland. These recordings were made using a Hewlett-Packard 3950B instrumentation recorder, using the FM mode on the red and green PACT video channels, resulting in much better recordings than those taken earlier with direct mode preamplifiers. The Dugway recordings provided ambient background samples for that geographical location, as well as controlled "hot test" recordings, while the Edgewood series provided a wide variety of agent simulants as well as a background sample for that location.

In addition to providing material for analysis and subsequent hardware design, these tapes provide a library of agent and background recordings for current and future use. Also the subsequent analysis outputs provide a potentially very useful supply of data for current and future applications.

It was originally planned to digitize selected portions of the tape recordings and analyze the digitized data for analysis using an IBM 360 computer at the Aerojet ElectroSystems facility in Azusa, California. However it was subsequently noted that the same analysis could be performed more efficiently, using the existing pattern recognition electronics together with some simple breadboard circuits. Such an approach permitted Organon Diagnostics personnel to have complete control over the data reduction and analysis and permitted the use of much larger statistical samples than might have been used on the IBM 360 since the latter would have required the digitization of all of the video data. Such a change of methodology in data reduction did not alter the program cost but did result in a shift in allocation of funds from material to labor expenses. Also it contributed to a delay in the hardware phase of the program because of the diverting of labor into the data reduction task.

The data reduction consisted primarily of two basic operations:

- Generation of video pulse height/pulse width distributions for various subjects.

- Generation of group density distribution information describing the occurrence of "groupiness" as well as particle sizes for various subjects.

The first of these operations provides guidelines for selection of thresholds on the Pulse Height/Pulse Width Discriminator developed under the earlier contract, while the second operation provides guidelines for analyzing the operation of the correlator, also developed in the previous program. The data thus obtained can be used also for analyzing the performance of the pattern recognition electronics for a specific agent with specific threshold settings.

These analytical results were used to analyze the operation of the correlator on a quantitative basis, using a Hewlett-Packard 9100B programmable calculator with a program simulating the operation of the correlator. Ultimately, after analyzing the correlator, it has been recommended that the AGC function be eliminated and that a pair of correlator profiles of different shape be used simultaneously with their functions combined through AND-gates.

The second major task of the program was the design, fabrication and checkout of an Alarm Logic System with two units initially to be delivered. Basically the Alarm Logic System provides the interface between the pattern recognition electronics and the operator. The system should be automatic so that it will alert the operator when conditions indicate a good likelihood of a challenge being present in the air. For this reason the Alarm Logic System must perform comparatively complex processing of the pattern recognition subsystem outputs according to a specific mathematical procedure, and it must be performing these functions continually. Basically the Alarm Logic System monitors four separate parameters continually:

- Total particle counts.
- Small particle counts.
- Large particle counts.
- Correlator counts.

Long term averages and short term averages are continually approximated for each of these four parameters, and the differences between long and short term averages are then compared between different parameters using a specific logic to determine if an alarm condition exists.

The third major task of the program was to refine the current pattern recognition electronics to reject mold spores while retaining a reasonable sensitivity to egg challenges which closely resemble mold spores as far as the pattern recognition electronics are concerned. Initially an approach which would make use of fine-grained internal structure within the egg clumps was considered; however, breadboard tests conducted on tape-recorded egg and mold spore video led to the conclusion that such structure was not readily observable with the PACT system.

After the examination of pulse height/pulse width distribution data obtained for agents and mold spores in the analysis portion of the program, a mold spore rejection circuit concept was devised which utilizes the characteristic of mold spores to exhibit high video pulse amplitude (i.e. high attenuation) at comparatively narrow pulse width. A Mold Spore Detector thus was devised which classifies particles as "large", i.e. as mold spores, if their characteristics place them above a line on a plot of pulse height versus pulse width, and "small", or potential challenges, if they fall below the line. This line is not straight, but starts out horizontally at a moderate level for low pulse width values and then slopes upward toward the right and then resumes a horizontal orientation for wide pulses. The positional parameters of this line are adjustable by means of four potentionmeters. Two units of this Mold Spore Detector initially were fabricated and this unit is operated in conjunction with the pattern recognition electronics and the Alarm Logic.

Finally, the fourth major task was to fabricate spare electronic hardware for the pattern recognition system. This included one duplicate of each type of plug-in card in the card cage assembly (a total of seven cards) and a third complete Alarm Logic System. This work was done on a program extension, together with further work on threshold analysis (task two above). Also, the retrofitting of the modified Pattern Recognition Systems was completed under this extension.

3.0 ANALYSIS

The first of three tasks conprising this program involved the tape recording and subsequent analysis of PACT video data to provide guidelines toward optimizing alarm/false alarm sensitivities of the pattern recognition system. This analysis augments the analysis performed earlier when Contract DAAA 15-72-C-0375 in that the current data is based upon high quality FM tape recordings of the PACT video outputs and utilizes much larger statistical samples in the subsequent analysis. Also the outputs of the analysis provide more useful information about a given agent than the previous work.

3.1 Data Acquisition

The data used in the analysis portion of this program was obtained at three recording sessions. The first of these was conducted at Dugway, Utah in June 1974; the second session was held at Edgewood Arsenal, Maryland in July 1974, and the third series of recordings was made at Dugway in August, 1974. These recordings provided a library of very high quality of a wide range of agents of interest.

3.1.1 Operating Conditions and Parameters

3.1.1.1 PACT System

The PACT system was adjusted to provide a 5-volt spider amplitude in the red video channel and a 4-volt amplitude in the green channel, as recommended in an earlier report.[1] Such an adjustment has been reported to provide a better detection/false alarm ratio on low-level red channel signals. This consideration also has been discussed in the earlier report.[2]

The operating parameters for the PACT system are taken as follows:

Scan line length - 100 microns

Scan frequency - 400 HZ

Spot velocity - 40 microsec/micron

Tape velocity - 2 inches/minute

3.1.1.2 Tape Recorder

The tape recorder used was a Hewlett-Packard 3950 B standard instrumentation tape recorder, which was taken to the three recording sessions by Organon Diagnostics. The machine has seven channel capability

1 Quarterly Report No. 1106-Q1, 8 December 1972, Section 3.2.2, pp. 33-40.

2 Ibid. Section 3.2.3, pp. 41-42.

on 1/2 inch tape, with three of the channels used in a given recording. This permitted using two sets of tracks on each tape, thereby doubling the recording time available per reel of tape. All recordings were made at 60 ips. Both red and green video channels were recorded in the FM mode which provided accurate preservation of the integrity of the video waveform which was not possible with the direct-mode recordings made on the previous program. The frequency response of the FM channels at 60 ips. is essentially flat from DC to 200 kHz. A third channel was used in the recordings in the direct-mode for voice announcements. The recordings were calibrated at each of the three sessions by recording the spider signal from the PACT device. With the exception of the first Dugway session, the channel configurations used in these recordings are as follows:

Side A:

Channel 1: Red video (FM mode)

Channel 2: Green video (FM mode)

Channel 3: Voice announcements (direct mode)

Side B:

Channel 5: Red video (FM mode)

Channel 6: Green video (FM mode)

Channel 7: Voice announcements (direct mode)

An index of tape recordings from the three sessions appears in Table 3-1. Since all of these recordings were made at 60 ips., the approximate duration of each recording can be determined from the footage counter readings given, recalling that 60 ips. equals 5 fps.

3.2 Single Pulse Parameter Analysis

The first portion of the analysis deals with the determination of the distributions of amplitude and width values for certain agents and backgrounds. Clearly, these values are determined to a large extent by the opacity of the stained organism and its physical dimensions, respectively, as the flying spot moves over them and is correspondingly attenuated, producing the video pulse at the output of the PACT system. Of course, the physical geometry of the flying spot and the position of a particular organism with respect to the trajectory of the spot will affect the video pulse height and width as well.

3.2.1 Purpose

The fundamental purpose of this phase of the analysis was to provide empirical data on pulse height and width which can be used to select the most desirable threshold settings of pulse height and width ranges for specific agents or groups of agents. It also provides a means of quantitatively determining the performance that would be obtained with specific agents and backgrounds for given pulse height/pulse width window settings. This analysis

TABLE 3-1 INDEX OF TAPE RECORDINGS

(A) FIRST DUGWAY RECORDING SESSION, JUNE 1974

RUN	SUBJECT	FOOTAGE COUNTER (Begin and End)	
	TAPE 2		
5	Calibration Signal (5 volt peak spider)	00000	00500
6	Background prior to the arrival of the Sm cloud (Trial 4)	00500	01500
6	Mark on tape for approximate arrival time of the Sm cloud (Trial 4)	01500	09000

TABLE 3-1 INDEX OF TAPE RECORDINGS (Cont.)

(B) EDGEWOOD RECORDING SESSION, JULY 1974

RUN	SUBJECT	FOOTAGE COUNTER (Begin and End)	
	TAPE 1A		
--	Calibration Signal 5V Peak	00000	00300
1	Dry Carbon (No Stain Process)	00300	02000
2	Wet Carbon (With Stain Process)	02000	04000
3	Wet Select Egg (VEE Simulant)	04000	08000
	TAPE 1B		
4	Wet Whole Egg (Q Simulant)	00000	04000
--	Calibration Signal 5V Peak	04000	04300
5	Wet Bg	04300	08000
	TAPE 2A		
6	Wet Sm	00000	04000
7	Wet Yeast	04000	06400
	TAPE 2B		
15	Dry Select Egg	00000	04000
16	Dry Sm	04000	08000

TABLE 3-1 INDEX OF TAPE RECORDINGS (Cont.)

	TAPE 3A		
8	Wet Mold Spore (size approximately 3 microns)	00000	02500
9	Wet Killed Pt Increased Concentration	04000 06460	06460 08000
	TAPE 3B		
17	Wet Select Egg	00000	04000
18	Outside Air Background 140 Liter Concentrator (Time 1130 Hrs., 18 July 1974)	04000	08500
	TAPE 4A		
10	Background Outside Air with 1000 Liter Concentrator (Time 1500 hrs., 17 July 1974)	00000	08000
11	Same Background as above but with lower concentration with 140 liter concentrator (Time 1515 hrs., 17 July 1974)	04000	08000
	TAPE 5A		
12	Outside Air Background with 140 liter concentrator (Time 0800 hrs., 18 July 1974)	00000	04000
13	Dry Bg	04000	08000
	TAPE 5B		
14	Dry Select Egg	00000	01500

TABLE 3-1 INDEX OF TAPE RECORDINGS (Cont.)

(C) SECOND DUGWAY RECORDING SESSION, AUGUST 1974

RUN	SUBJECT	FOOTAGE COUNTER (Begin and End)	
	TAPE 1A		
--	Spider Calibration 5V Peak	00000	00200
1	Sm	00210	1670
2	Sm	1680	3133
3A	VEE (real test) Mark 6 = Approx. 700 counts per 10 sec. gate	3800	5300
4	VEE (heavier concentration)	5310 (900 marks per gate)	6760
5	VEE (heavier concentration than Run 4)	6770 (approx. 1200/10 sec. gate)	
6	Q Low Concentration	0000 (1st minute not recorded)	1385
7	Q Slightly higher concentration	1400	2895
8	Q Higher concentration than Run 7	2905	4400
9	Q Approx. twice the 2X concentration of 8	4410	5905
10	Q Higher concentration than 9	5915	7440
--	Backwash of Q Very high concentration	7450	8960
11	Pt	0000	1467
12	Pt (higher concentration than 11)	1480	2968
13	Pt (New Aerosol)	2980	4458
14	Pt	4470	5938
15	Pt	5950	7445

also provided the basis for the concept for the Mold Spore Rejection System which was developed under this contract. The Mold Spore Rejection System is described in Section 4.2.

3.2.2 Initial Procedure

Using the new recordings, two dimensional statistical distributions of pulse height/pulse width values were generated. In the first procedure employed to do this, the tapes were played through one of the "windows" of the Pulse Height/Pulse Width Discriminator. In generating these distributions, the expected region of values is divided first into four large adjacent windows and the tape is played for the agent of interest and the fraction of the red counts coming through that window is calculated from the readouts on the counters. This is repeated for each of the three remaining windows. Subsequently, those windows where the greatest detection rates occur are subdivided into smaller and smaller windows, and the fraction of the red counts coming through each particular window is determined. This process is continued until a sufficiently detailed picture of the statistical distributions for pulse height and pulse width has been generated for that particular agent.

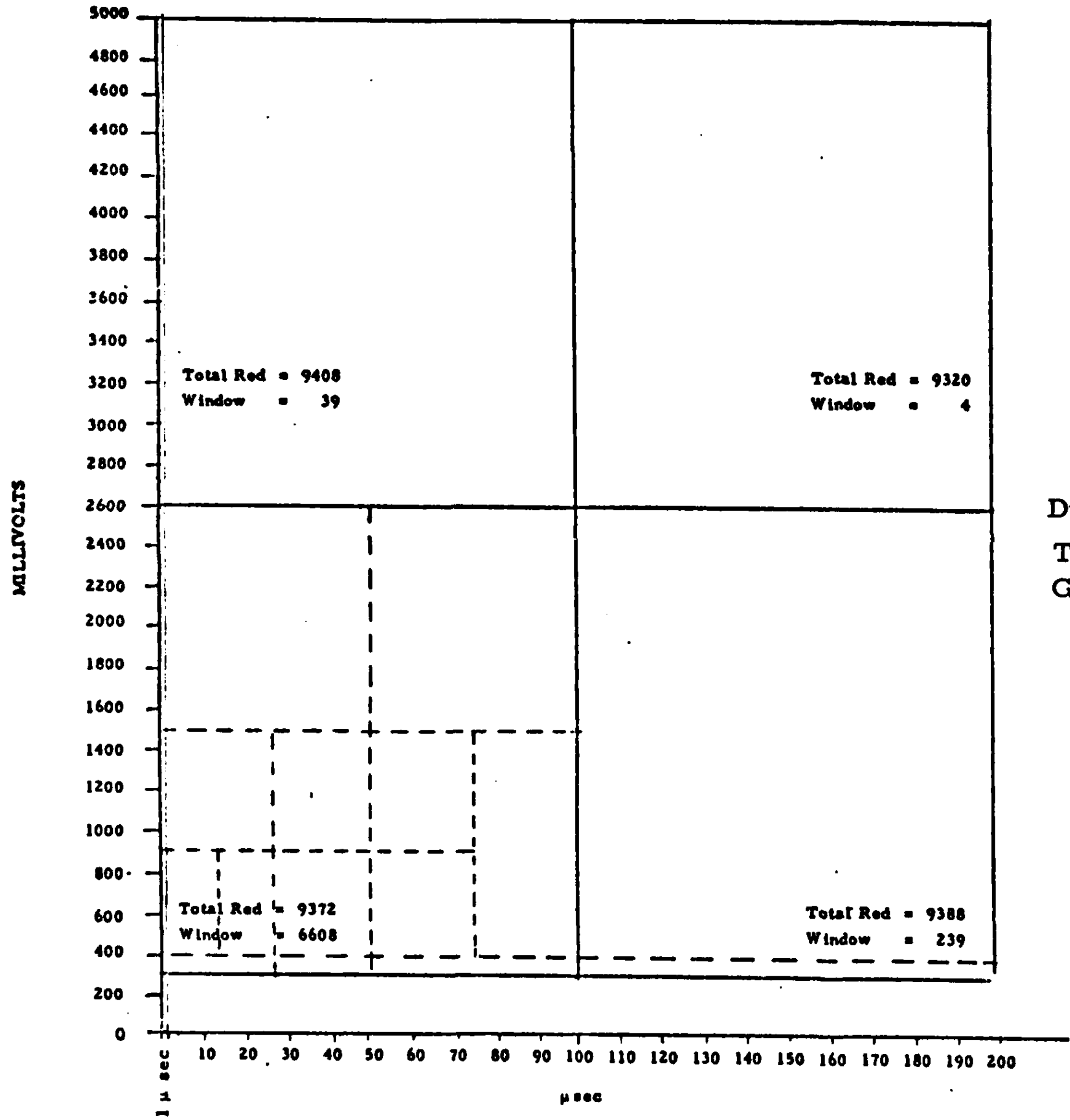
3.2.3 Initial Pulse Parameter Distribution Plots

Figure 3-1 shows the method of generation of an occurrence rate distribution by the above procedure and Figures 3-2 through 3-9 show a series of completed plots. One output was the generation of these distributions for various agents. While similar, one-dimensional distributions were generated on the preceding program, they do not show the interaction between the two parameters since they are only one-dimensional. Also, they are not as accurate since they were based upon direct mode tape recordings instead of FM (frequency modulation). Finally it should be noted that the use of the electronic equipment itself instead of the IBM 360 computer faciliates the use of much larger statistical samples and gave Organon Diagnostics complete control of the analysis situation.

The plots in Figure 3-2 through 3-9 show the rate density of pulses (i.e. the fraction of the total pulses coming through a window of unit dimensions of one volt high and one microsecond wide) for a window centered at a point of so many volts and microseconds. This rate density is plotted as a function of pulse width for several voltage levels. Of course the rate densities pertain only to the particular point in question (in volt-microsecond space) so that a window actually would need to be very much smaller than the "unit" window to experience an essentially uniform rate density over its entire area. For large windows, one can simply take an average of the rate values over its area and then multiply this average by the area of the window in volts and microseconds to obtain the rate through the entire window.

3.2.4 Second Procedure

During the extension of the program, the decision was made to use a different technique for pulse height/pulse width data reduction and plotting. While the initial procedure just described is capable of giving a fairly good overall picture of the occurrence distributions of pulses for various agents, this new approach provides the following advantages:



Dugway Background Only

Tape No. 2 Footage = 6500-7500

Gate Time = 3 min, 30 sec

Figure 3-1 Analysis Format for Pulse Height/Pulse Width Data Reduction (First Procedure)

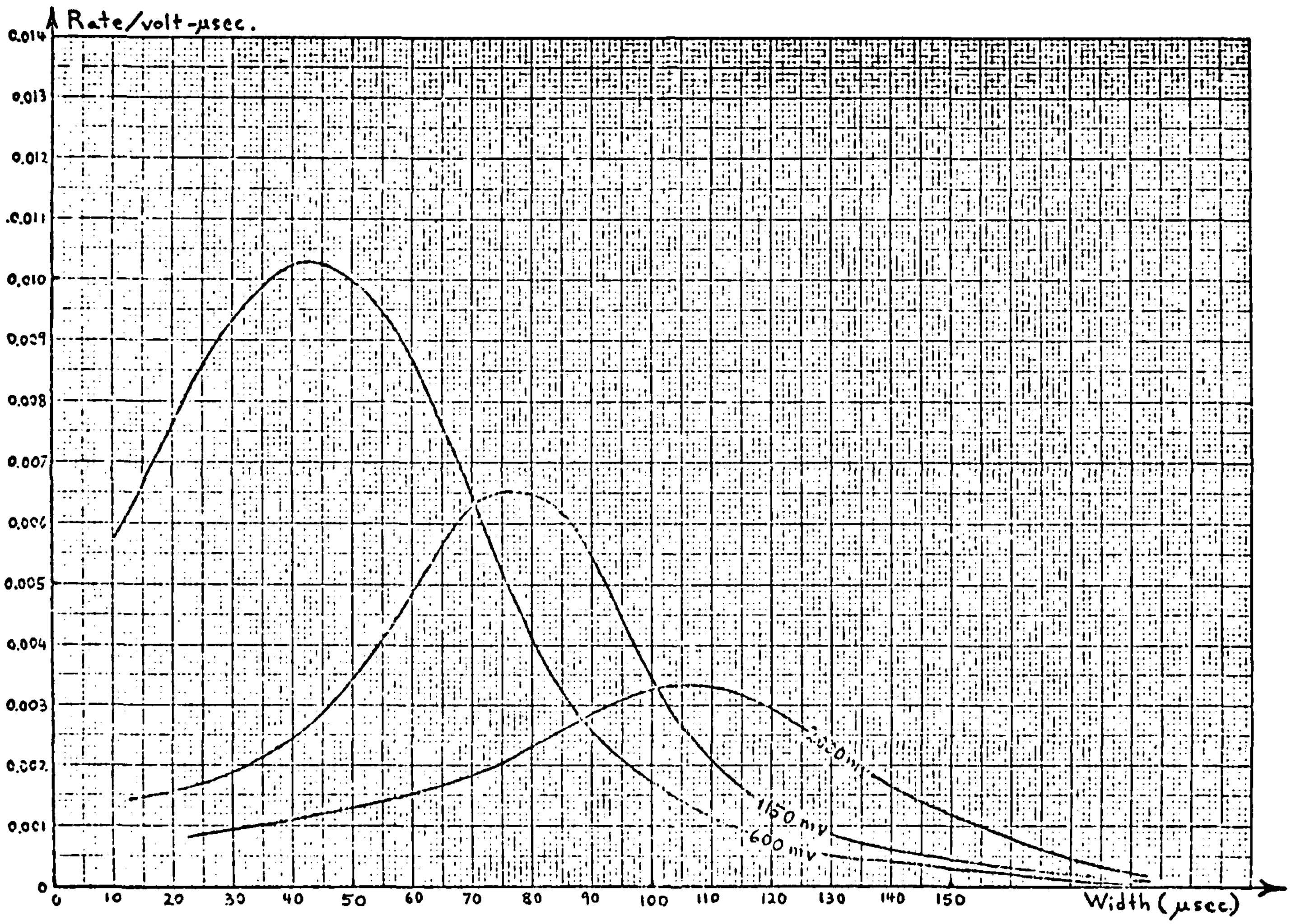


Figure 3-2 Wet Select Egg Pulse Parameter Distribution

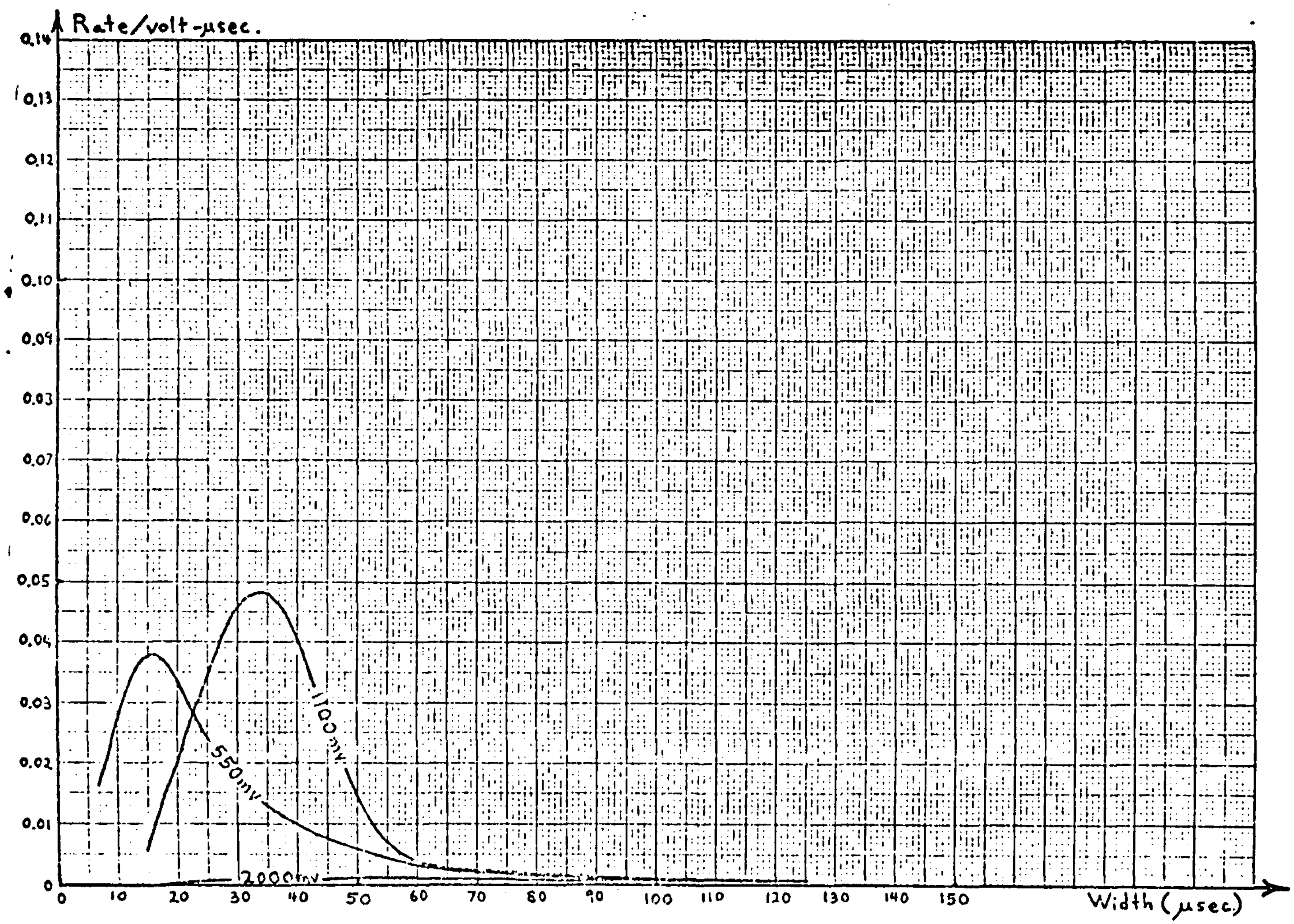


Figure 3-3 Wet Sm Pulse Parameter Distribution

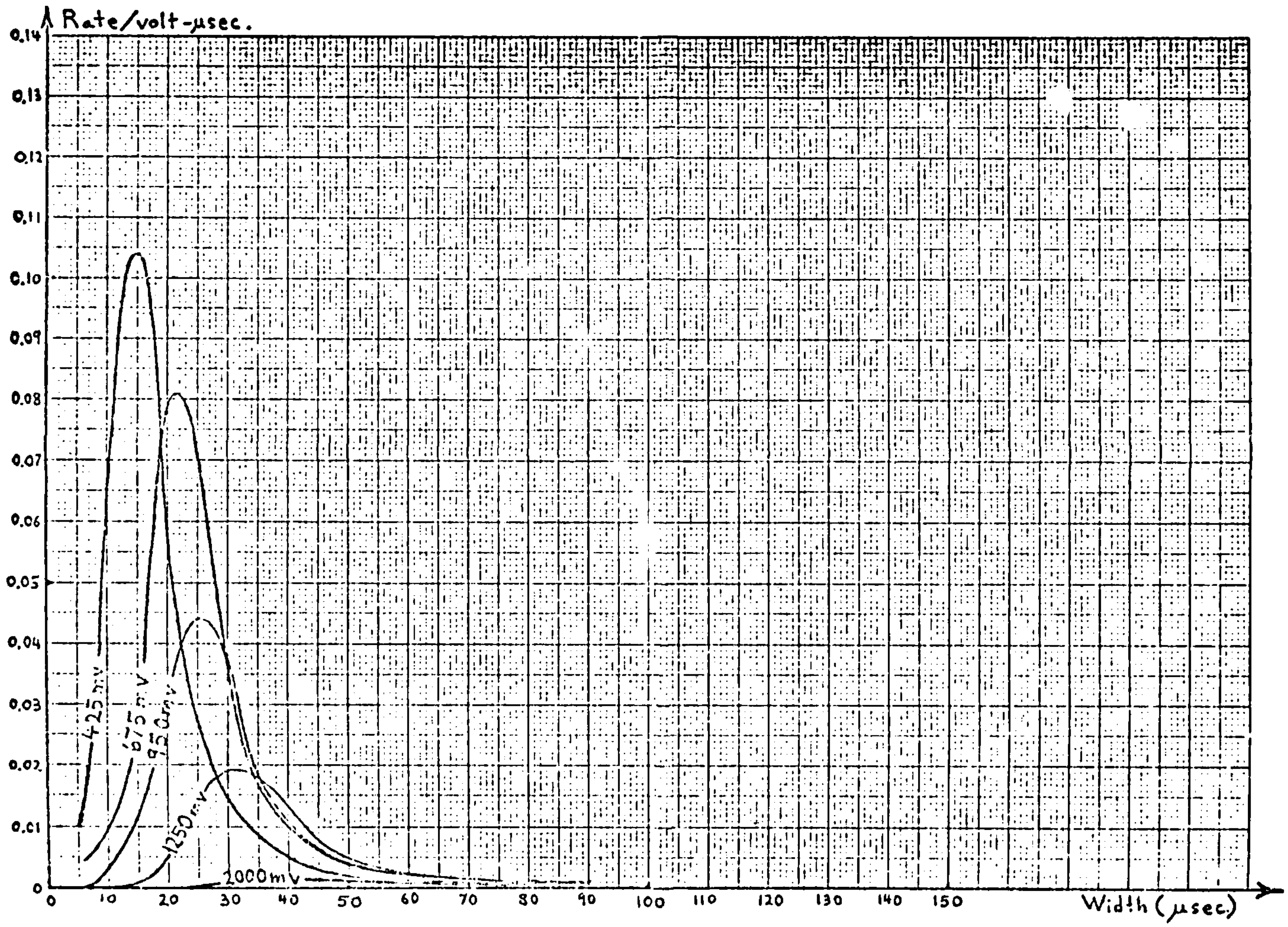


Figure 3-4 Wet Killed Pt Pulse Parameter Distribution

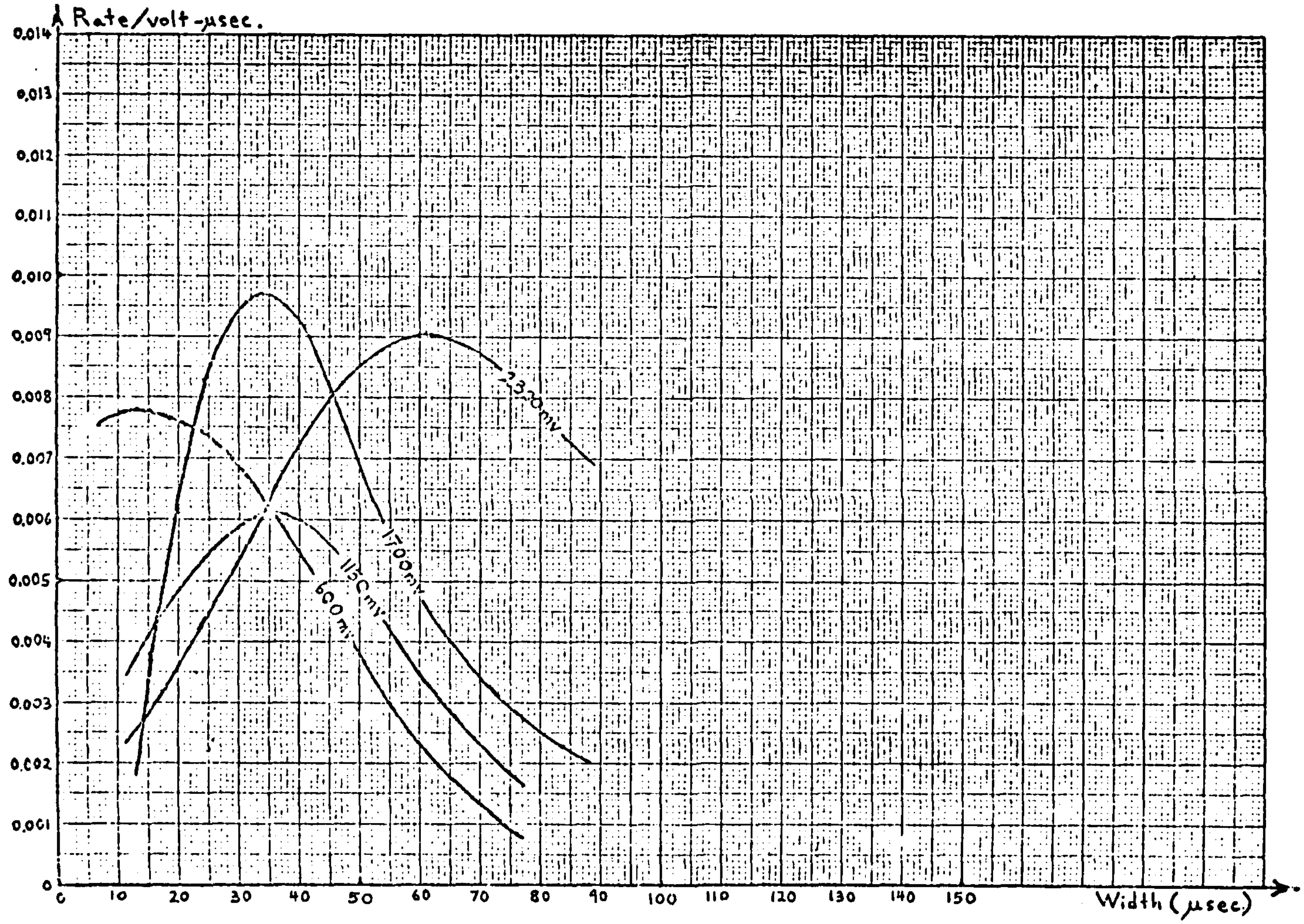


Figure 3-5   Dry Select Egg Pulse Parameter Distribution

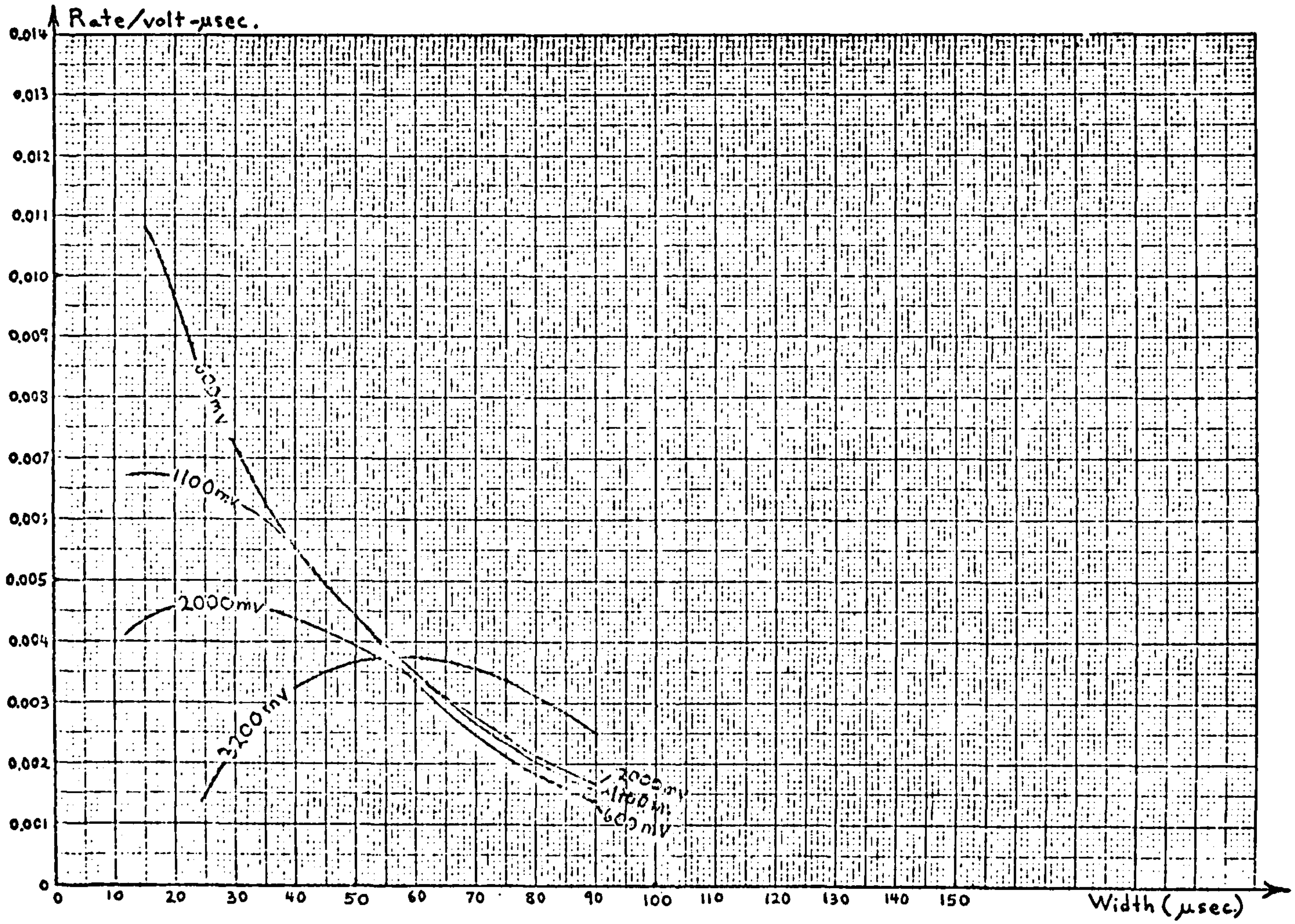


Figure 3-6 Wet Yeast Pulse Parameter Distribution

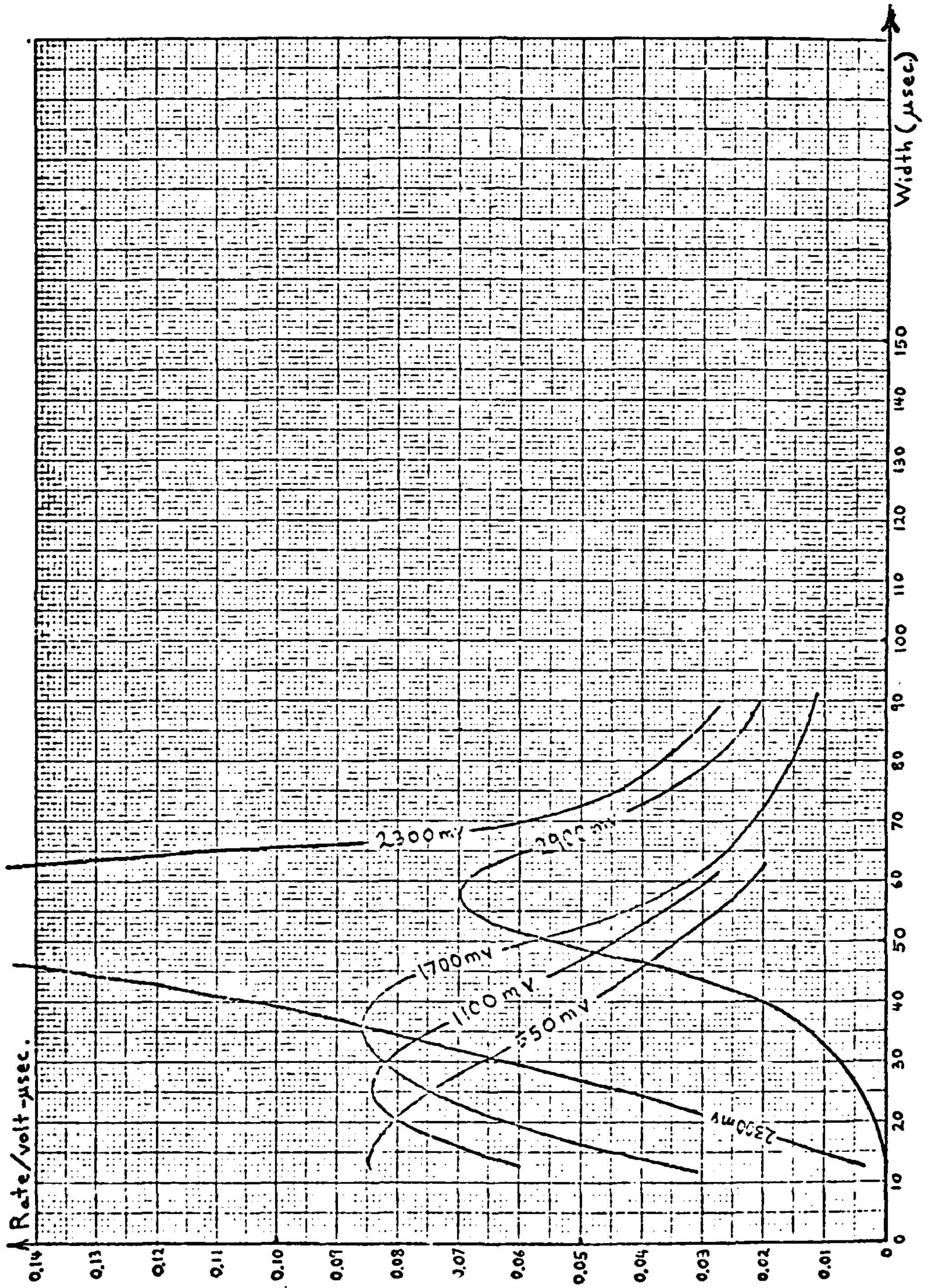


Figure 3-7 Wet Mold Spore Pulse Parameter Distribution

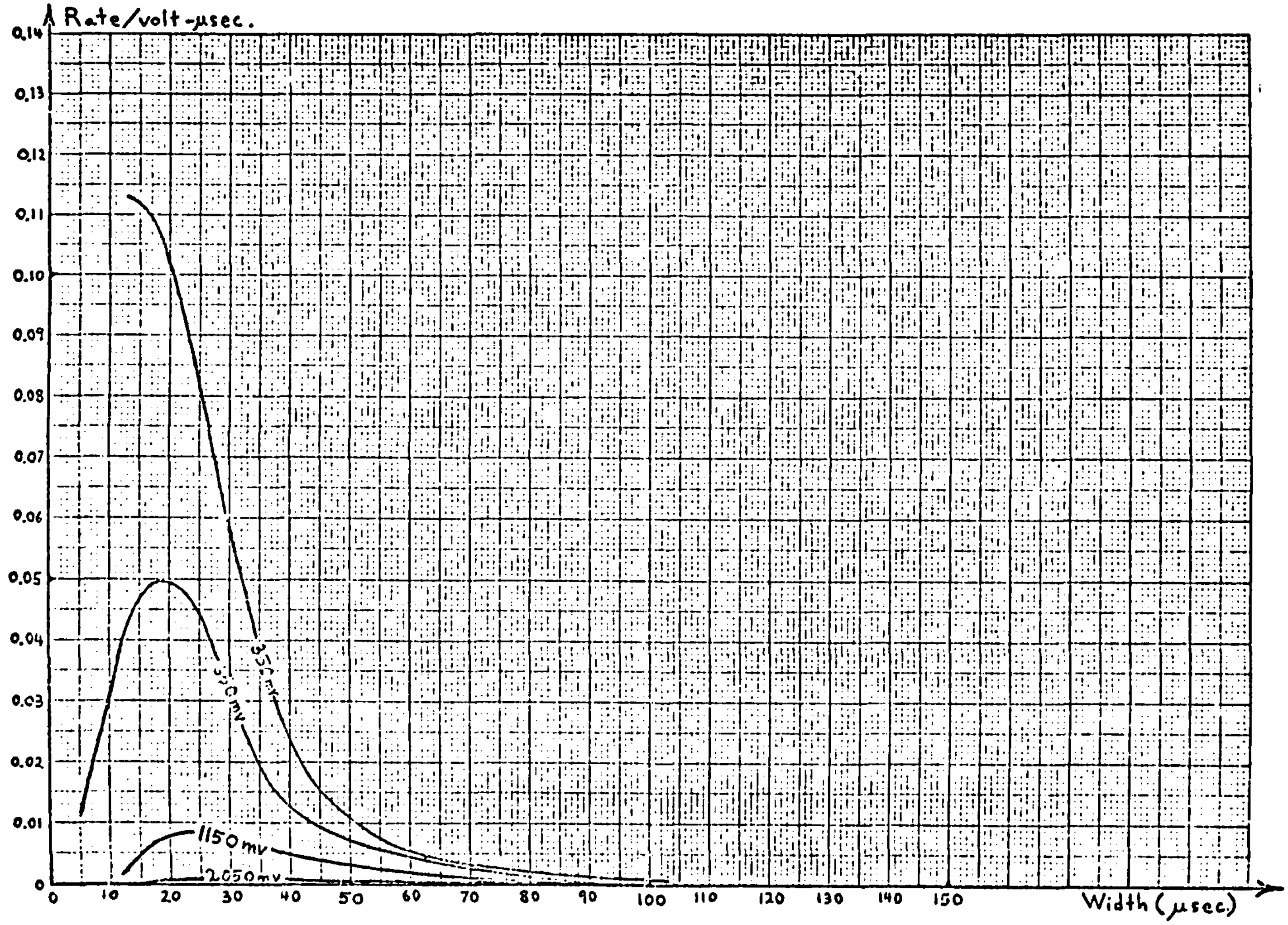


Figure 3-8 Dugway Background Pulse Parameter Distribution

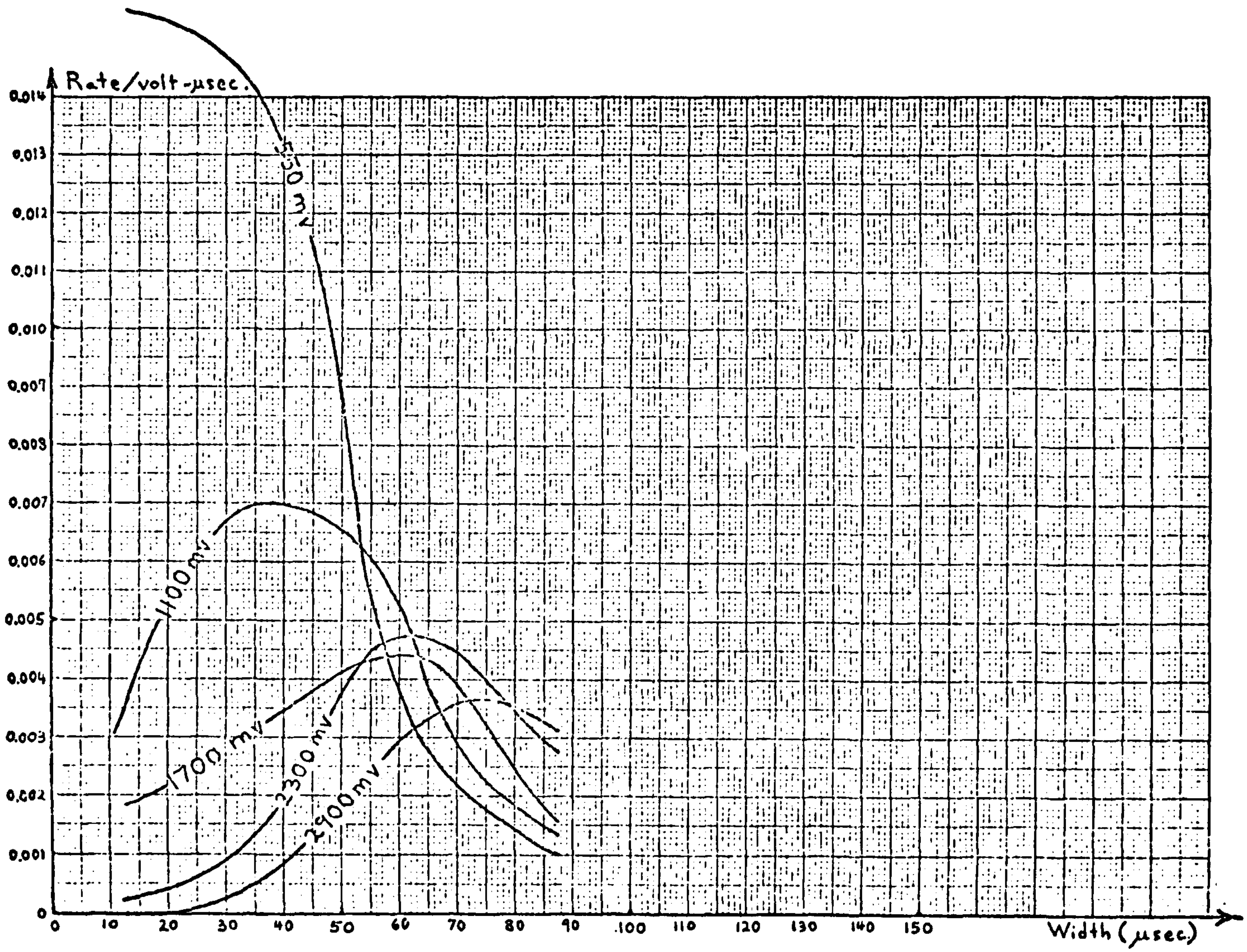


Figure 3-9 Edgewood Background Pulse Parameter Distribution

- Ready adaptability to computer plotting of data.
- Ready adaptability to plotting of contour maps of data distributions.

The format used in the new approach is illustrated in Figure 3-10. Here we have a chart of the pulse height/pulse width plane in which a large array of small windows of equal size are shown. Each window measures approximately 100 millivolts high by 5 microseconds wide. To implement this approach each of the three windows of the Pulse Height/Pulse Width Discriminator was adjusted to these dimensions and each window was monitored by a separate counter. During each run of the tape each window was placed in the place of an element of an array of which Figure 3-10 is typical. After a given run, each window was moved to occupy an element location not previously monitored. This process was continued until the desired amount of data was collected.

Since the windows are small, a more accurate measure of the rate density at the point in question is possible with this method whereas large windows simply can give an average of this value over their area. The approach just described, originally was devised for computer plotting, hence the equally spaced, equal sized windows of small size. This process was implemented, using a Hewlett-Packard HP9100B programmable calculator and the companion 9125A plotter. A program was written under this contract for plotting the data. The program takes six data values (i.e. ordinate values y_1 through y_6) which are equally spaced along the abscissa, while assuming a seventh data point $y_o = 0$ at $x = 0$. However, in some cases, the program was adapted to work with a nonzero value for y_o. Based on the method of Lagrange coefficients, the program plots an equation which passes through all seven data points.

3.2.5 Computer Plots of Pulse Parameter Distributions

Data was taken for wet Sm, dry select egg, wet select egg and wet mold spore, using the procedure discussed above and depicted in Figure 3-10. These agents appear from the earlier results of Section 3.2.3 to be fairly representative of the range of types of agents. The primary purpose of choosing the egg and mold spore samples for this more detailed analysis was to provide inputs for upgrading the performance of the mold spore detector, considered a priority item during the extension of this contract.

The results of the data plots using the HP9100B-9125A combination appear in Figures 3-11 through 3-16. Figures 3-11 through 3-14 are similar in format to Figures 3-2 through 3-9 except that a relative scale is used for the occurrence rate (ordinate); also the horizontal scale and contours are different. Figures 3-15 and 3-16 show the same data as Figures 3-12 and 3-14 except that they depict rate of occurrence plotted as a function of pulse height for various pulse widths. One word of caution should be made with reference to the use of the computer plotted curves. Since they represent equations passing through the data points they can show spurious or inaccurate dips or peaks between data points.

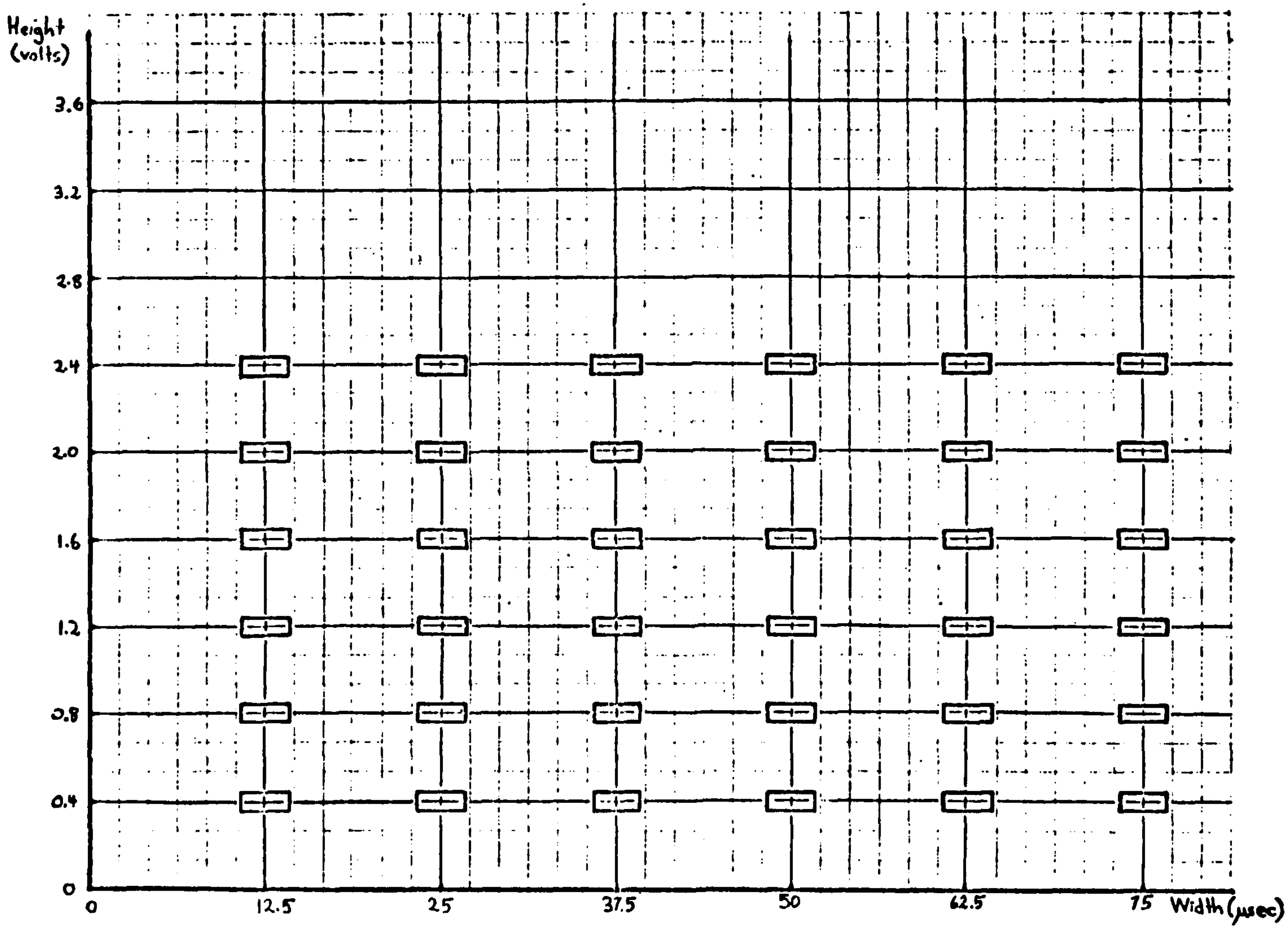


Figure 3-10 Analysis Format for Pulse Height/Pulse Width Data Reduction (Second Procedure)

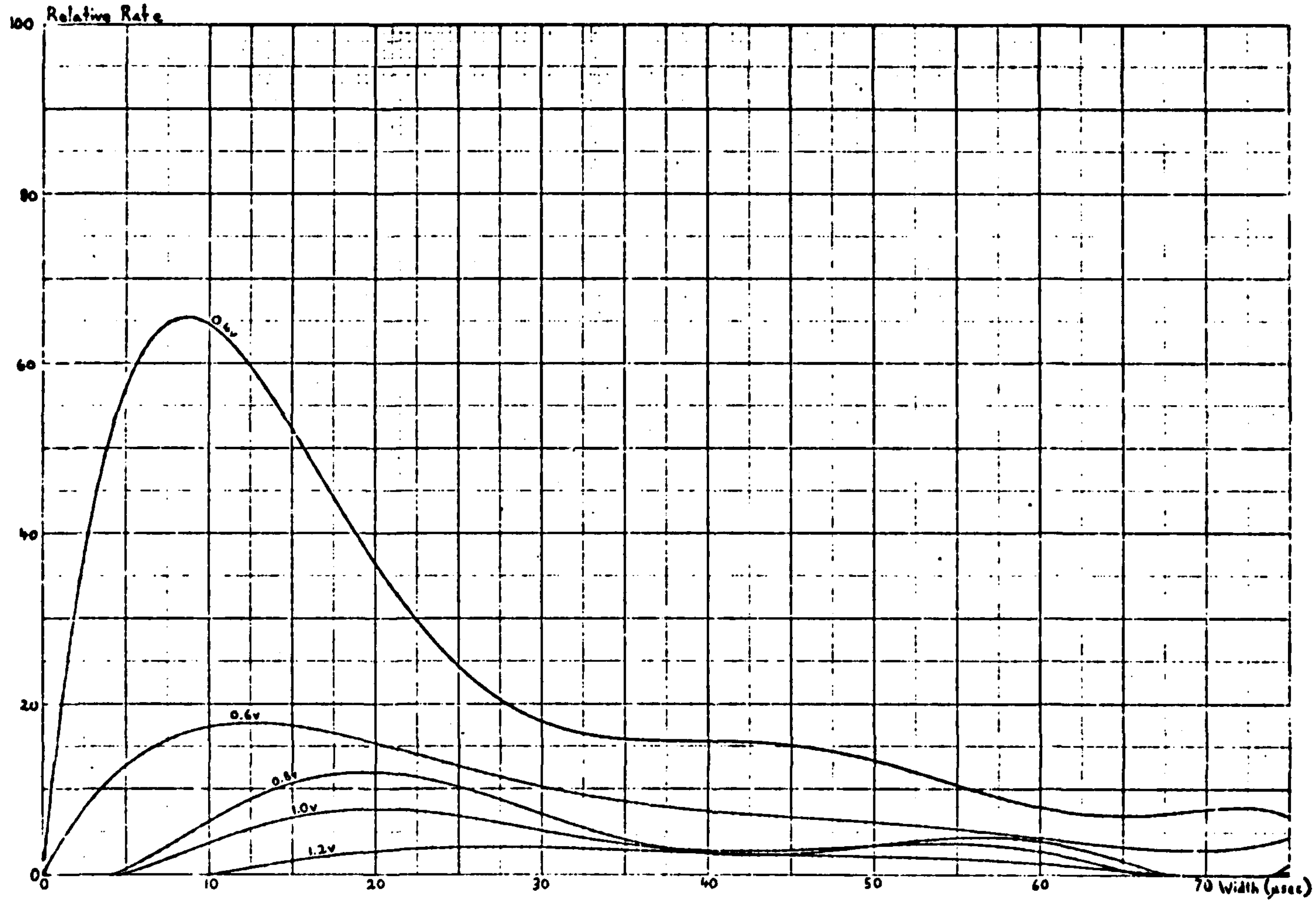


Figure 3-11 Wet Sm Pulse Parameter Distribution

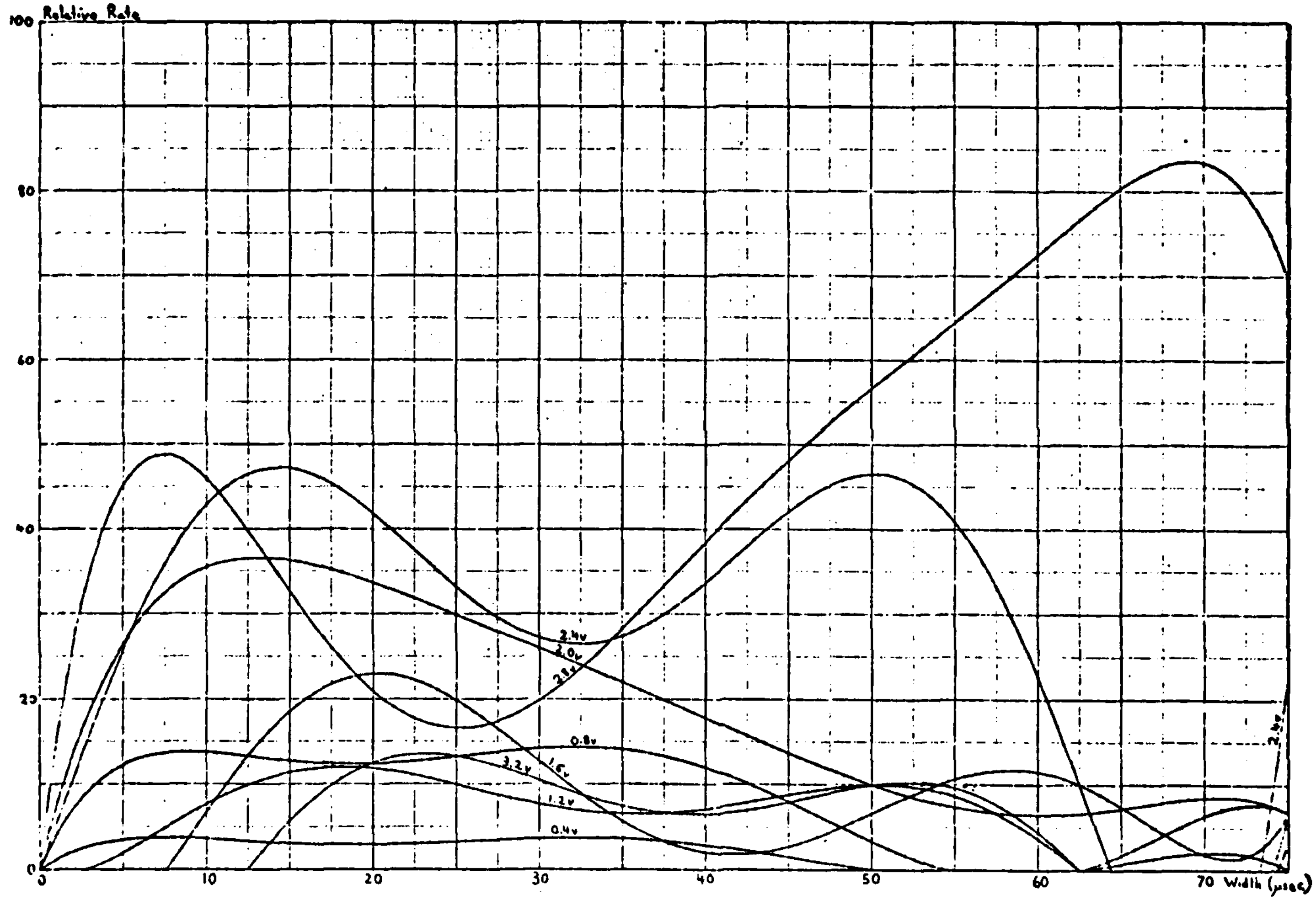


Figure 3-12 Dry Select Egg Pulse Parameter Distribution

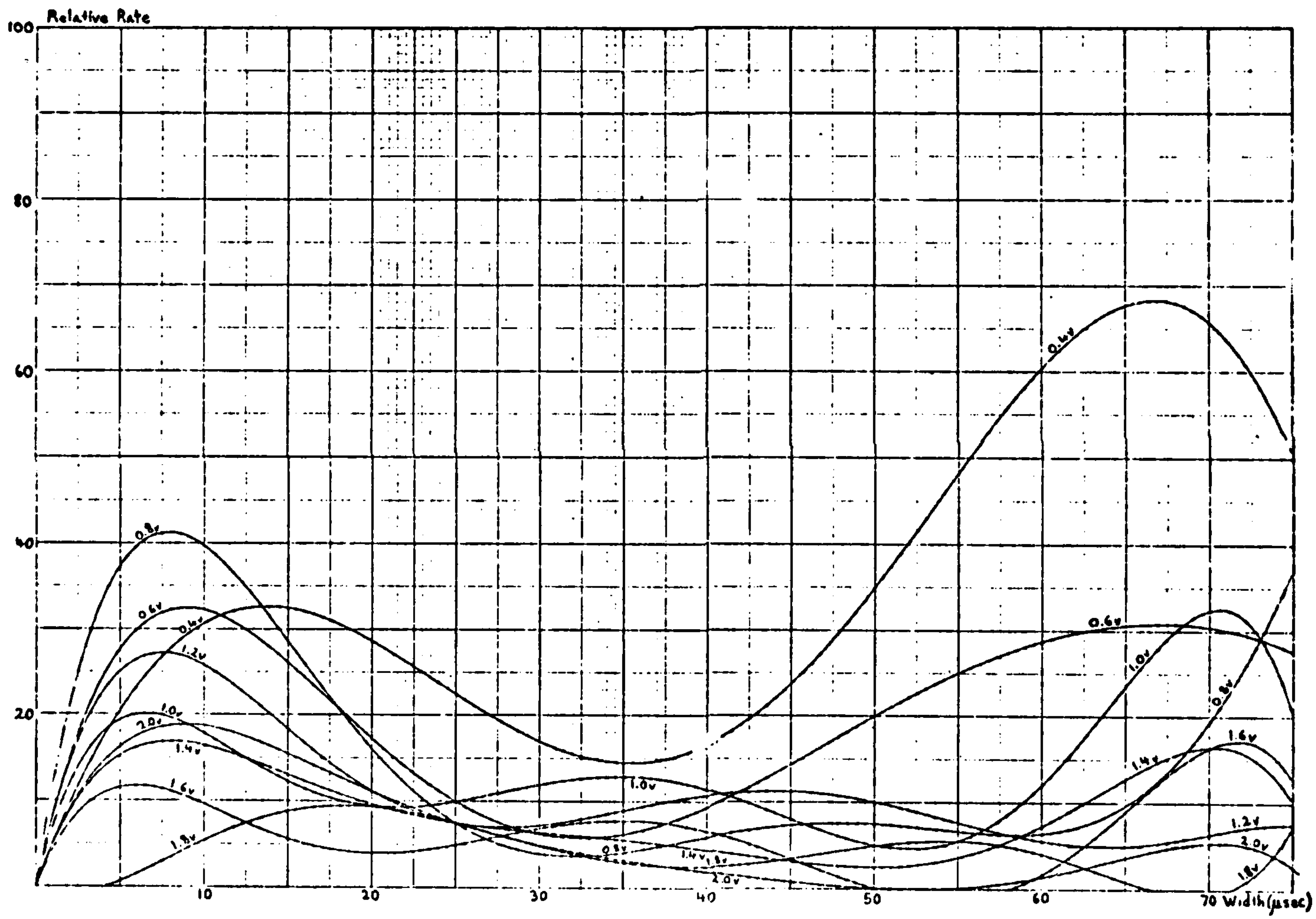


Figure 3-13 Wet Select Egg Pulse Parameter Distribution

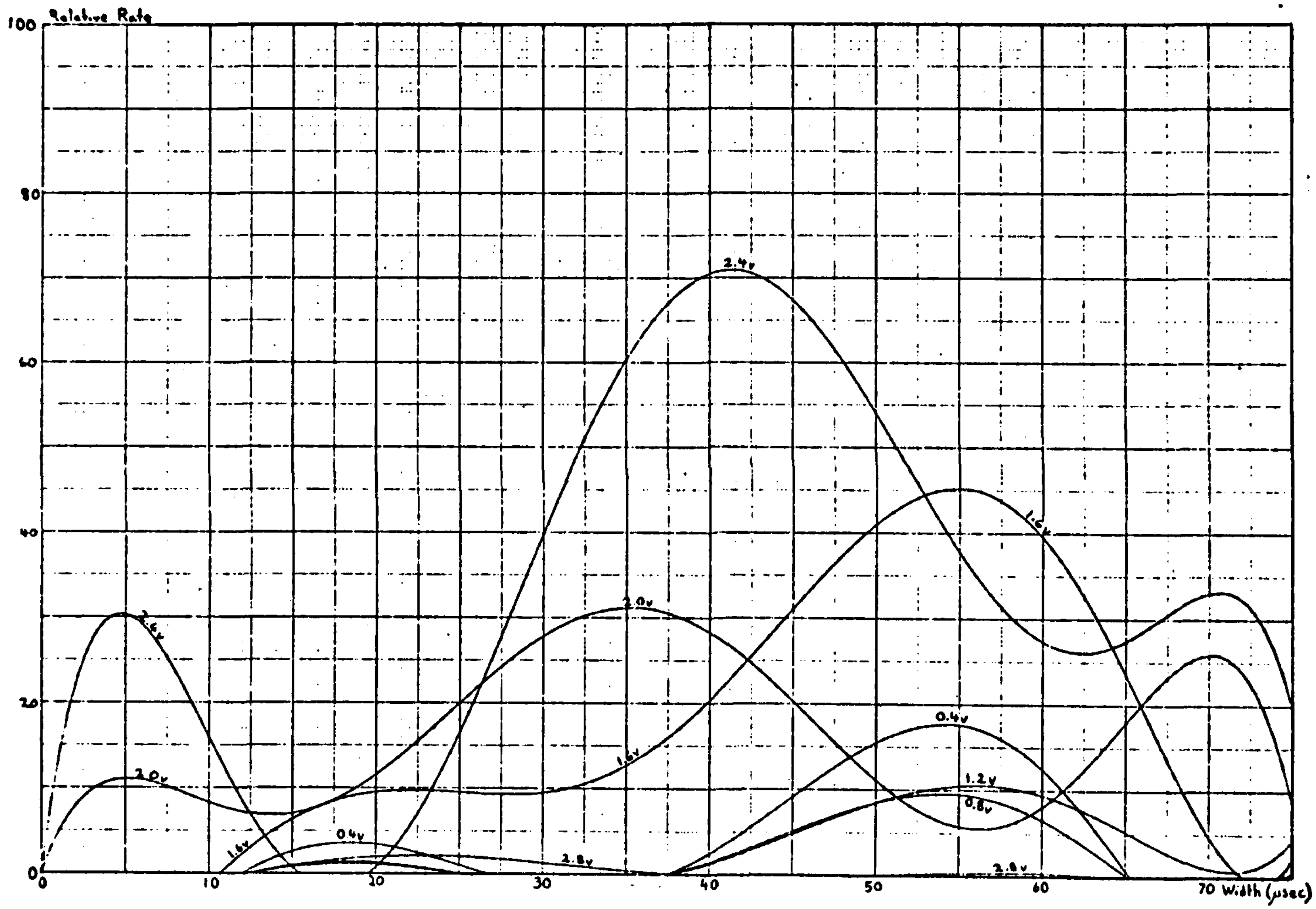


Figure 3-14 Wet Mold Spore Pulse Parameter Distribution

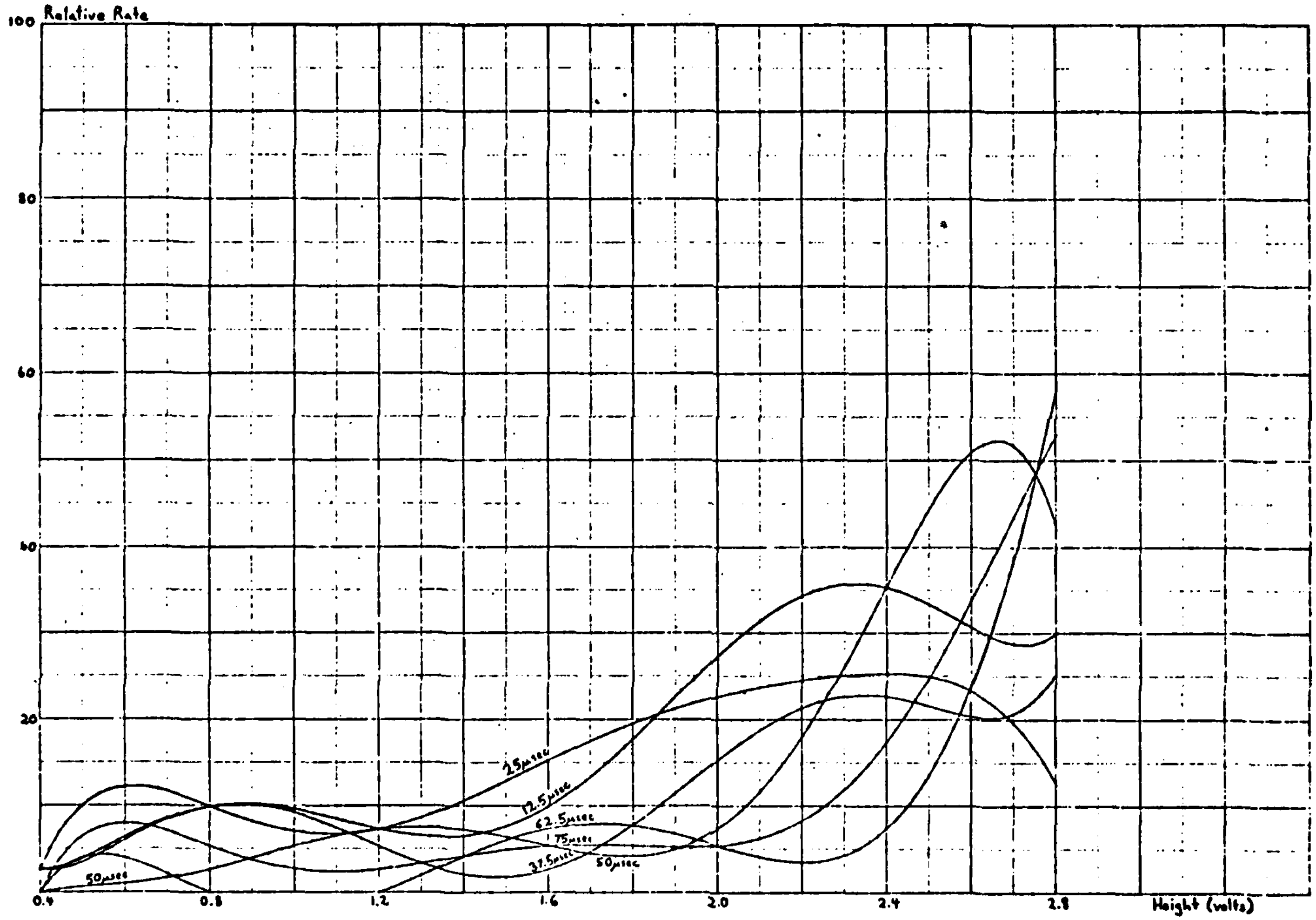


Figure 3-15 Dry Select Egg Distribution Versus Pulse Height

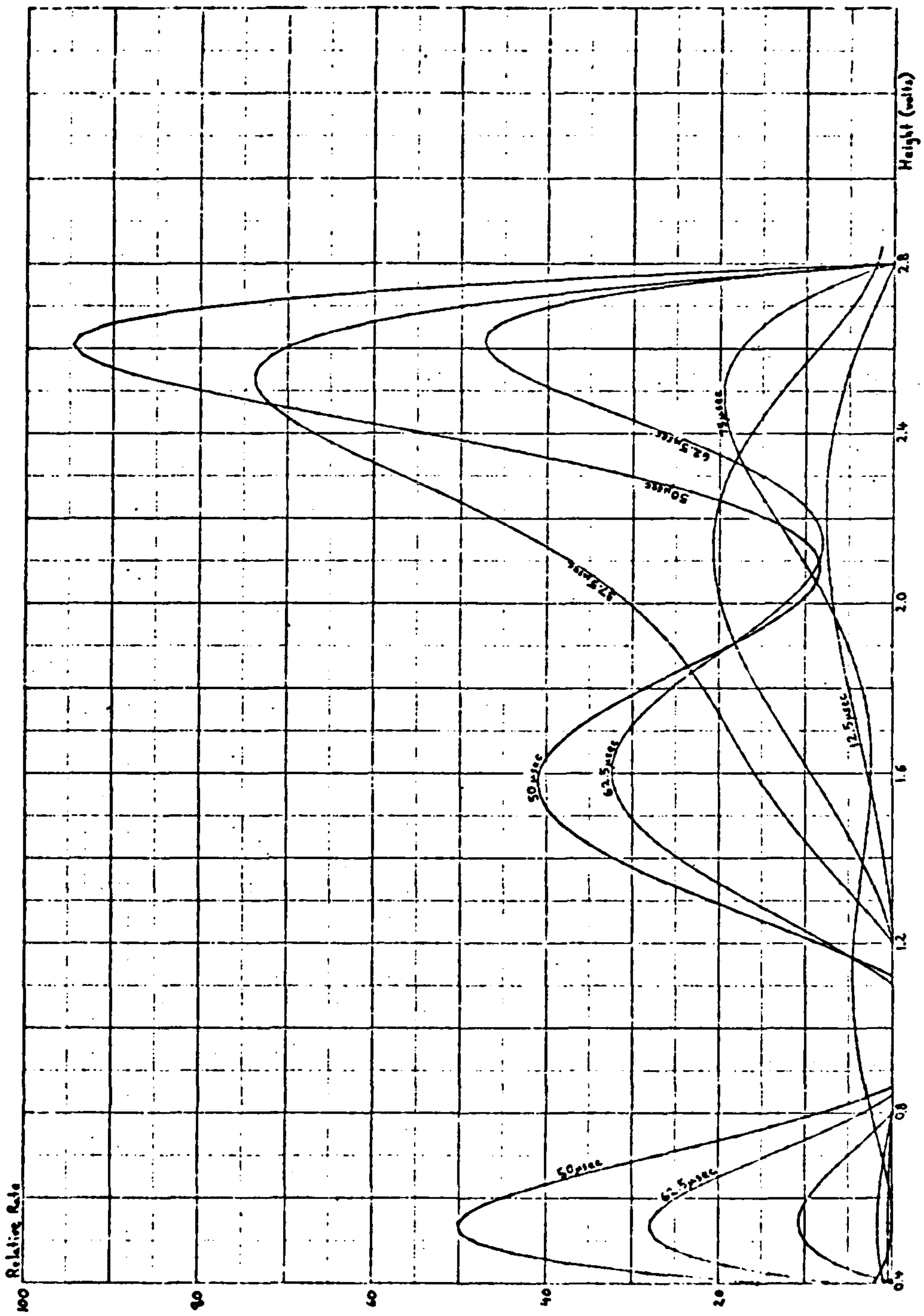


Figure 3-16 Wet Mold Spore Distribution Versus Pulse Height

The relationships between the various curves can be grasped more readily if one regards the data for a particular agent as plotted in the form of a three-dimensional solid, using three mutually orthogonal axes. The vertical axis is rate of occurrence and the horizontal axes are pulse height and pulse width. Figures 3-2 through 3-9 and 3-11 through 3-14 represent sets of curves resulting from slicing the solid by sets of vertical planes parallel to the rate-of-occurrence/pulse-width plane at the indicated points along the pulse-height axis. Similarly, Figures 3-15 and 3-16 represent slices of the same solid by planes parallel to the rate-of-occurrence/pulse-height plane at the indicated points along the pulse width axis.

3.2.6 Contour Plots

It has been found that the data taken by the procedure described in Section 3.2.4 lends itself readily to density contour plotting. This type of plot may be regarded as a third view of the three-dimensional solid just described in which the observer is viewing the solid in a direction normal to the pulse-height/pulse-width plane and the solid is sliced by different planes parallel to that plane at different intercepts along the rate-of-occurrence axis, thereby generating contours.

The contour plots, for wet Sm, dry select egg, wet select egg and wet mold spore appear in Figures 3-17 through 3-20. These plots are laid out in the identical manner as Figure 3-10. In each plot, a number indicating the percentage of all counts through all of the small windows appears at the location of each window. These windows were located at the intersections of the heavy lines as indicated, and in the case of wet Sm and wet select egg were located at the indicated midpoints as well (see Figure 3-17 and 3-19). With these percentages indicated, it was possible to sketch in contour lines giving the approximate geometry of the three-dimensional solid. The number associated with a given contour references the density level of the rate of occurrence in terms of the percentage of counts through all windows that a window might intercept within that contour (but outside of the next higher level contour).

It is easily seen that these contour plots can be extremely useful in deciding threshold positions for both the Pulse-Height/Pulse-Width Discriminator and the Mold Spore Detector. Threshold selection for the Mold Spore Detector is discussed further in Section 5 of this report.

3.3 Pulse Group Parameter Analysis

3.3.1 Purpose

The purpose of this subtask has been to establish the distribution profiles for both the x-correlator and the y-correlator for various agents of interest. Clearly, the results of this task also provide the basis for refining the choice of the correlator window dimensions in both the x and y directions as well as the correlator resistor network values for both x and y. As with the preceding subtask, this analysis procedure was performed by Organon Diagnostics using the PACT electronics instead of a computer.

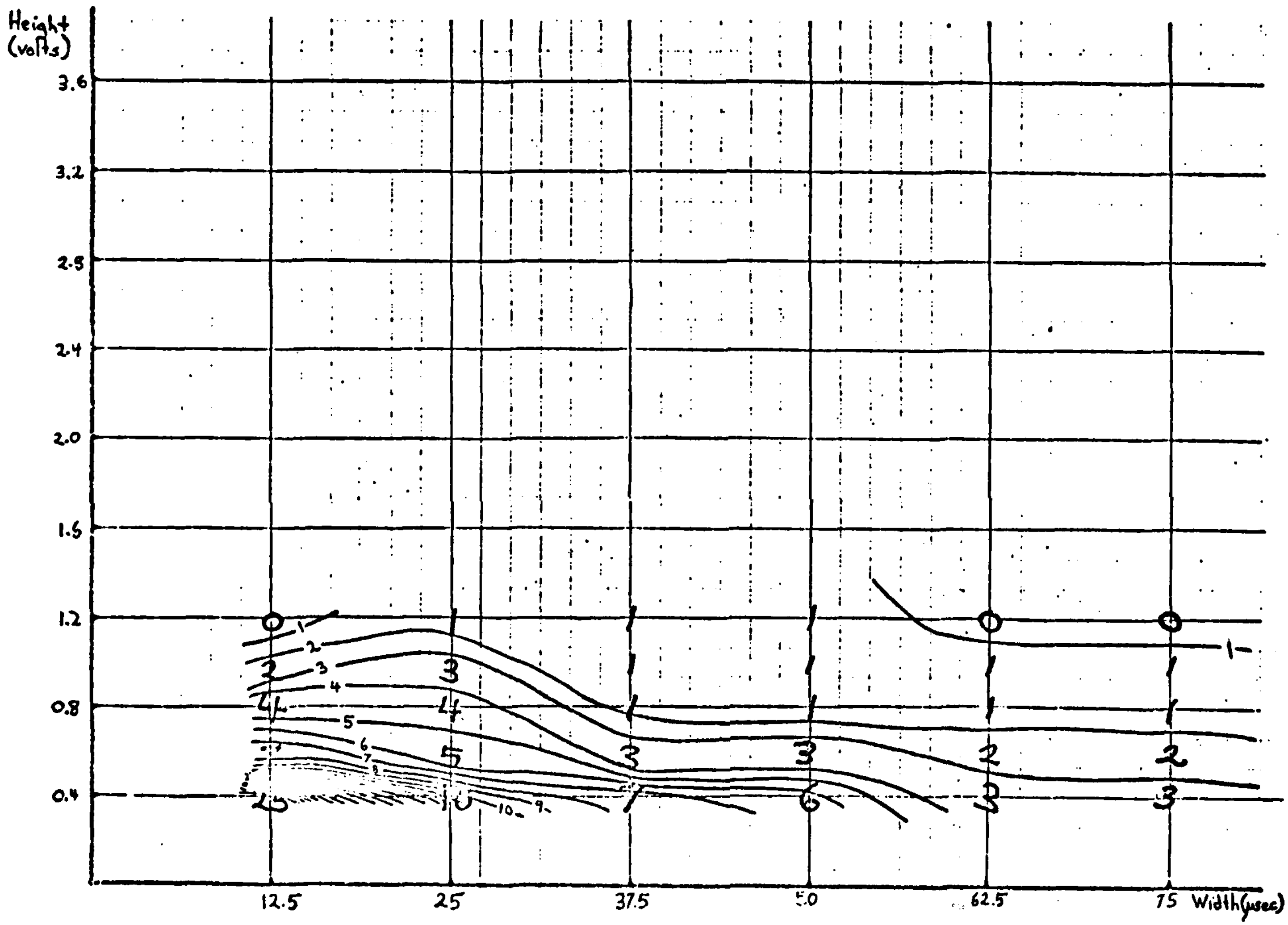


Figure 3-17 Wet Sm Rate-of-Occurrence Contour Plot

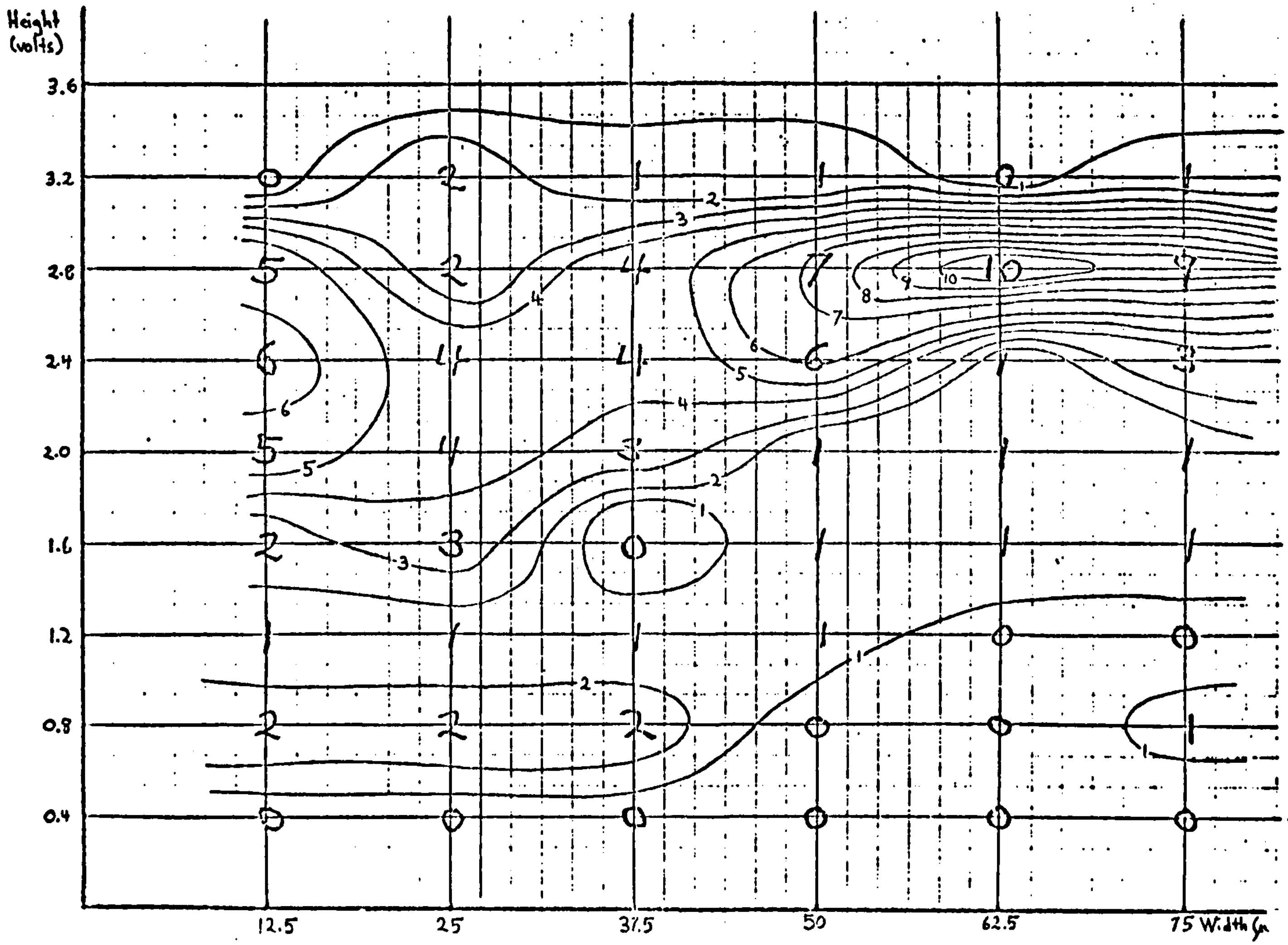


Figure 3-18 Dry Select Egg Rate-of-Occurrence Contour Plot

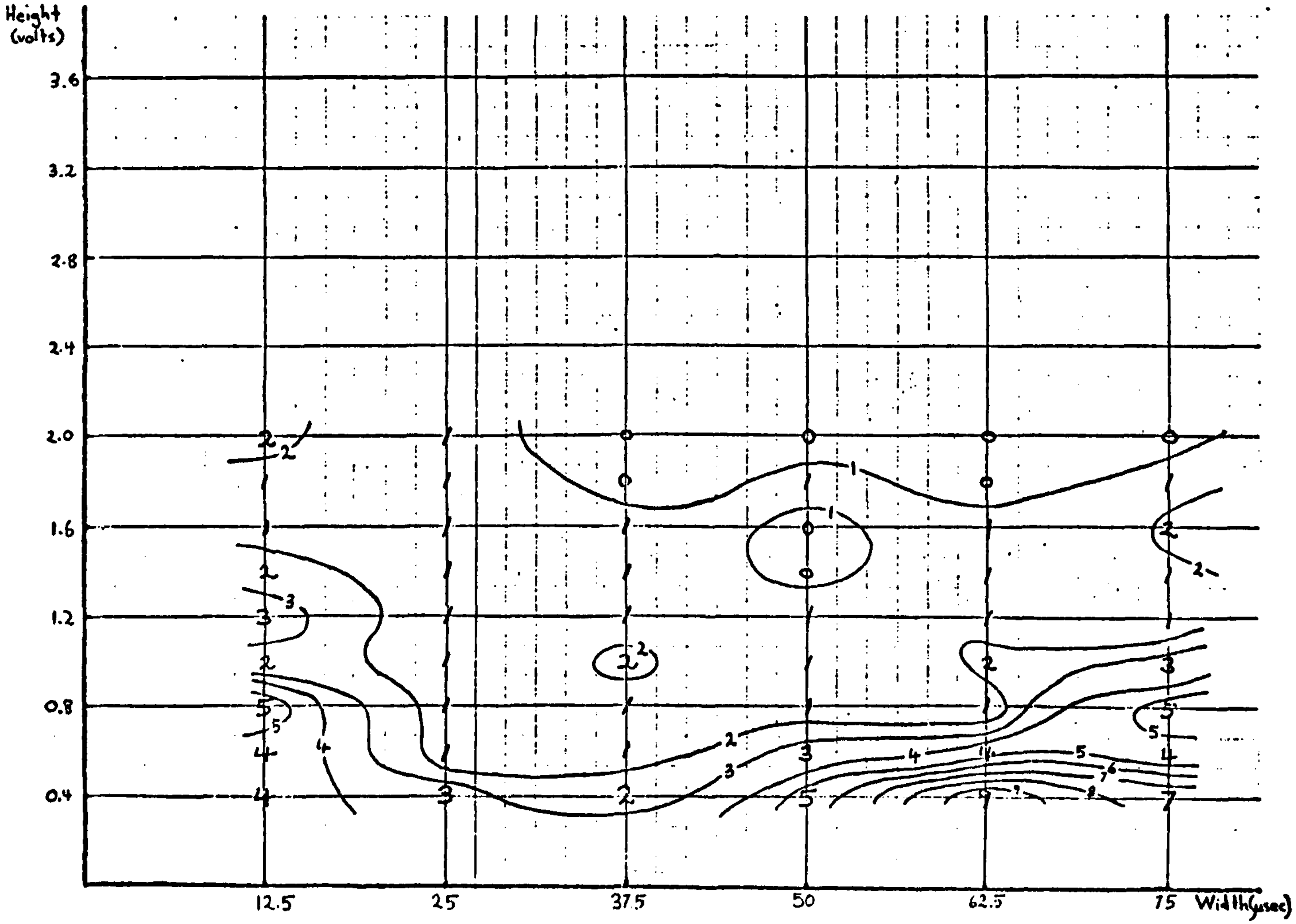


Figure 3-19 Wet Select Egg Rate-of-Occurrence Contour Plot

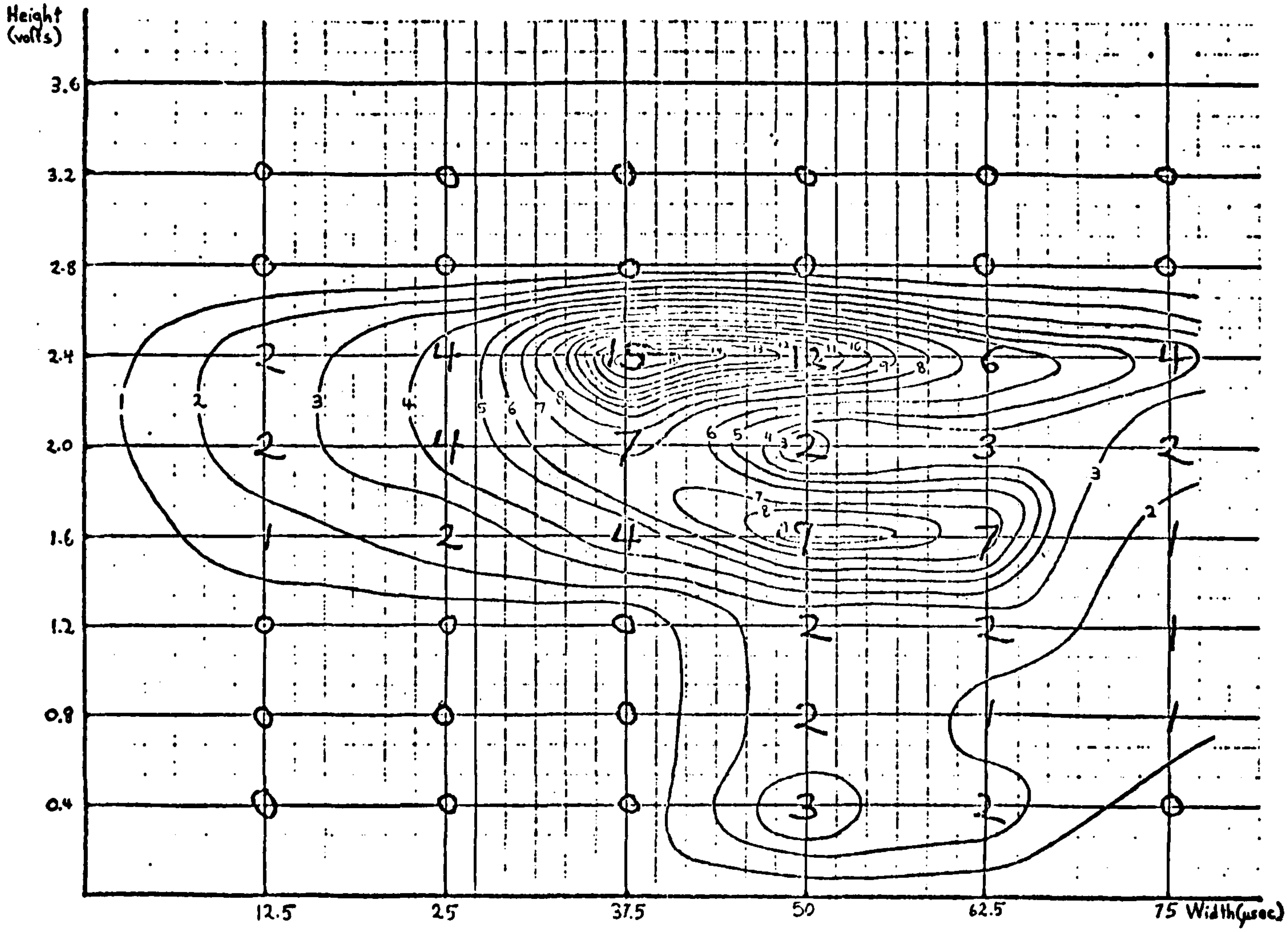


Figure 3-20 Wet Mold Spore Rate-of-Occurrence Contour Plot

3.3.2 Procedure

The subtask was performed by playing PACT video recordings of selected subjects through the pattern recognition electronics but without the Pulse Height/Pulse Width Discriminator and with the correlator AGC disabled. The 4 by 10 correlator window of the original configuration was used. To obtain X-profile data, the sum of one column is monitored and for the y-profile data the sum of one row is monitored. Figure 3-21 illustrates diagrammatically this operation. Here the 4 by 10 correlator "window" is shown as it "views" a hypothetical portion of the PACT tape. This window is commutated in 24 increments across the tape (downward in Figure 3-21) during one scan interval and moves over one increment and repeats the downward scan during the next scan interval. It is clear that the sum of the contents of one row will generate the y-profile of a clump over which it passes, if monitored during the period of one vertical scan. Similarly, to obtain the x-profile, the sum of one column is monitored. However, due to the scanning format, the situation here is more complex. This column is, in effect, scanned lengthwise through the clump during one scan interval generating a voltage peak as it passes over the clump. On each successive scan through the clump, a peak is generated with the height of the peak generally being a measure of the x-profile of the clump at that point along the x-axis. Thus the envelope of a series of peaks gives the x-profile of the clump.

In order to reduce the data, two auxiliary breadboard circuits were required. These are shown in Figure 3-22. For the y-axis (see Figure 3-22 (a)) the correlator output is fed into an adjustable threshold detector which passes only the portion of the waveform which is above an adjustable threshold. The signal that passes the threshold detector also is "squared up" by the detector. This signal is fed to an integrator which generates a voltage proportional to the duration of the signal. The output of the integrator is fed to another adjustable threshold circuit which is used to pass only those signals whose time duration is in excess of the value determined by the setting of the threshold on the second detector. Thus the net result of the circuit in Figure 3-22 (a) is to provide a count for each y-correlator output whose amplitude equals or exceeds the set minimum number of counts "c" and whose duration equals or exceeds the set minimum.

A similar circuit for the x-correlator is shown in Figure 3-22 (b). The major difference here is the use of a resettable one-shot multivibrator, necessitated by the fact that here it is necessary to look at a series of voltage peaks formed during a series of successive scans as described above. The time delay of the one shot is slightly greater than one scan period so that an uninterrupted series of voltage peaks will produce a continuous voltage plateau whose duration equals that of the series of peaks plus the delay time of the one shot. This plateau is then integrated and the result is threshold detected as before. Allowance, of course, had to be made for the added duration of the one-shot delay.

Figures 3-23 and 3-24 show a hypothetical case for x and for y, respectively. The waveforms which are fed to the circuits of Figure 3-22 are shown at the bottom of either figure. Figures 3-23 and 3-24 serve as more detailed illustrations of the situation of Figure 3-21. These

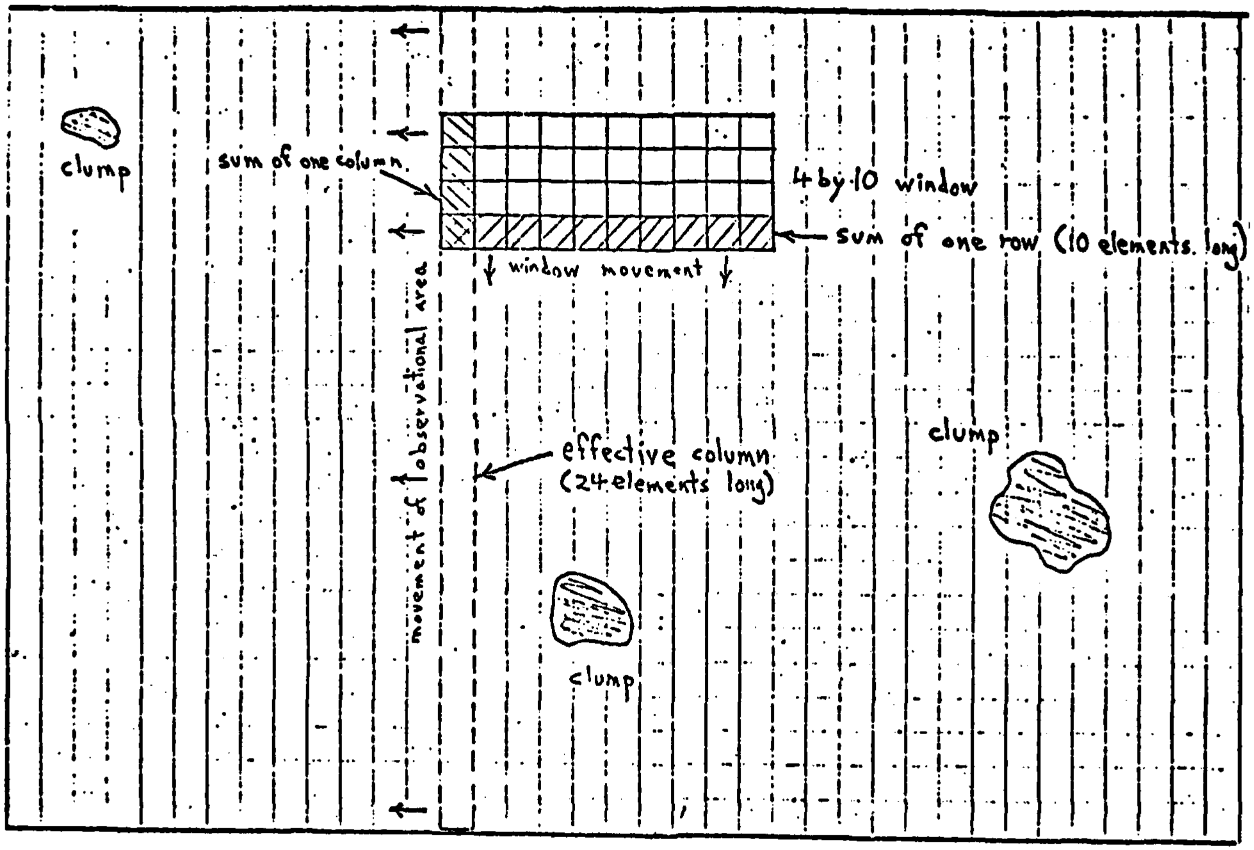


Figure 3-21 Pulse Group Analysis Plan

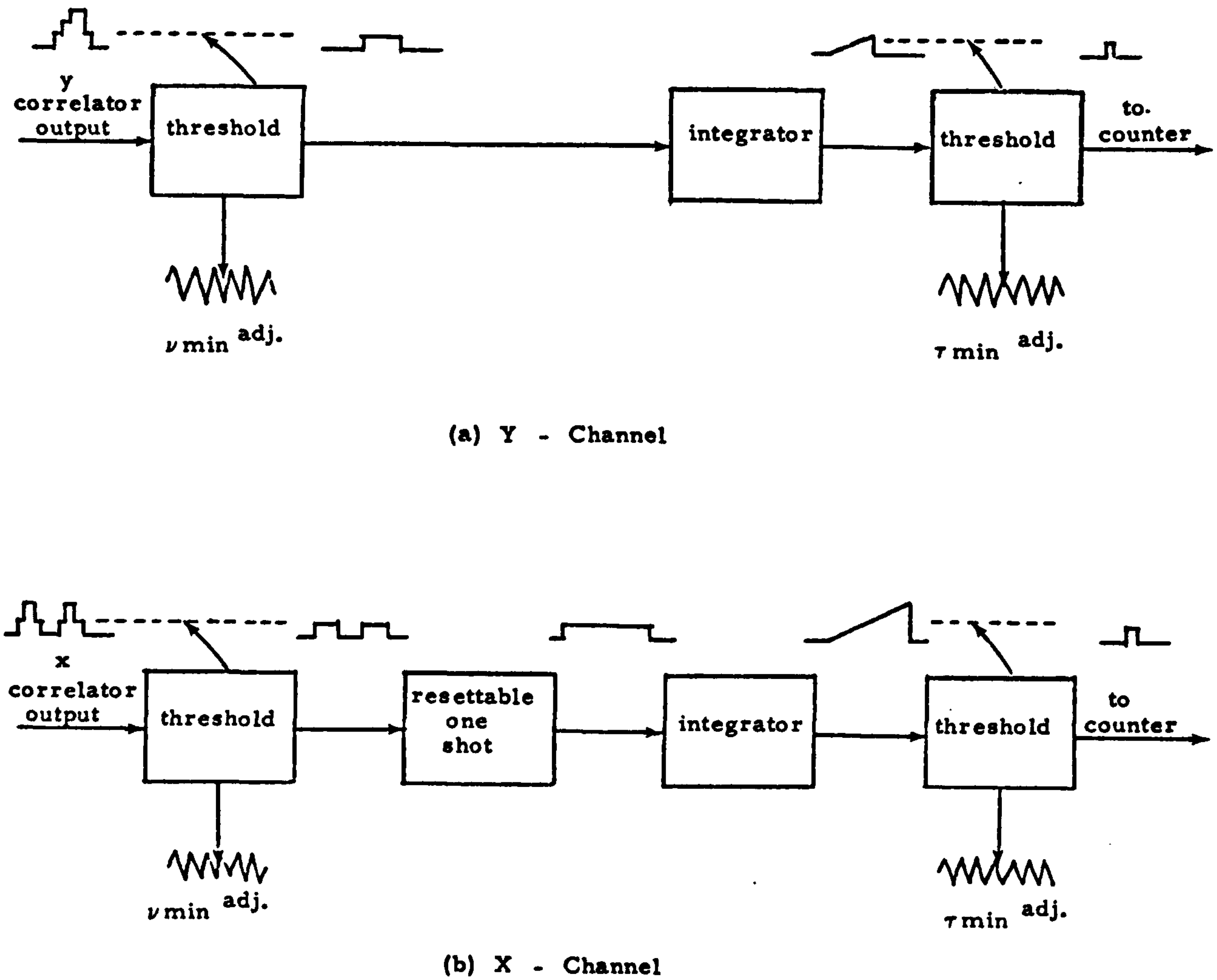


Figure 3-22 Pulse Group Analysis - Auxiliary Circuits

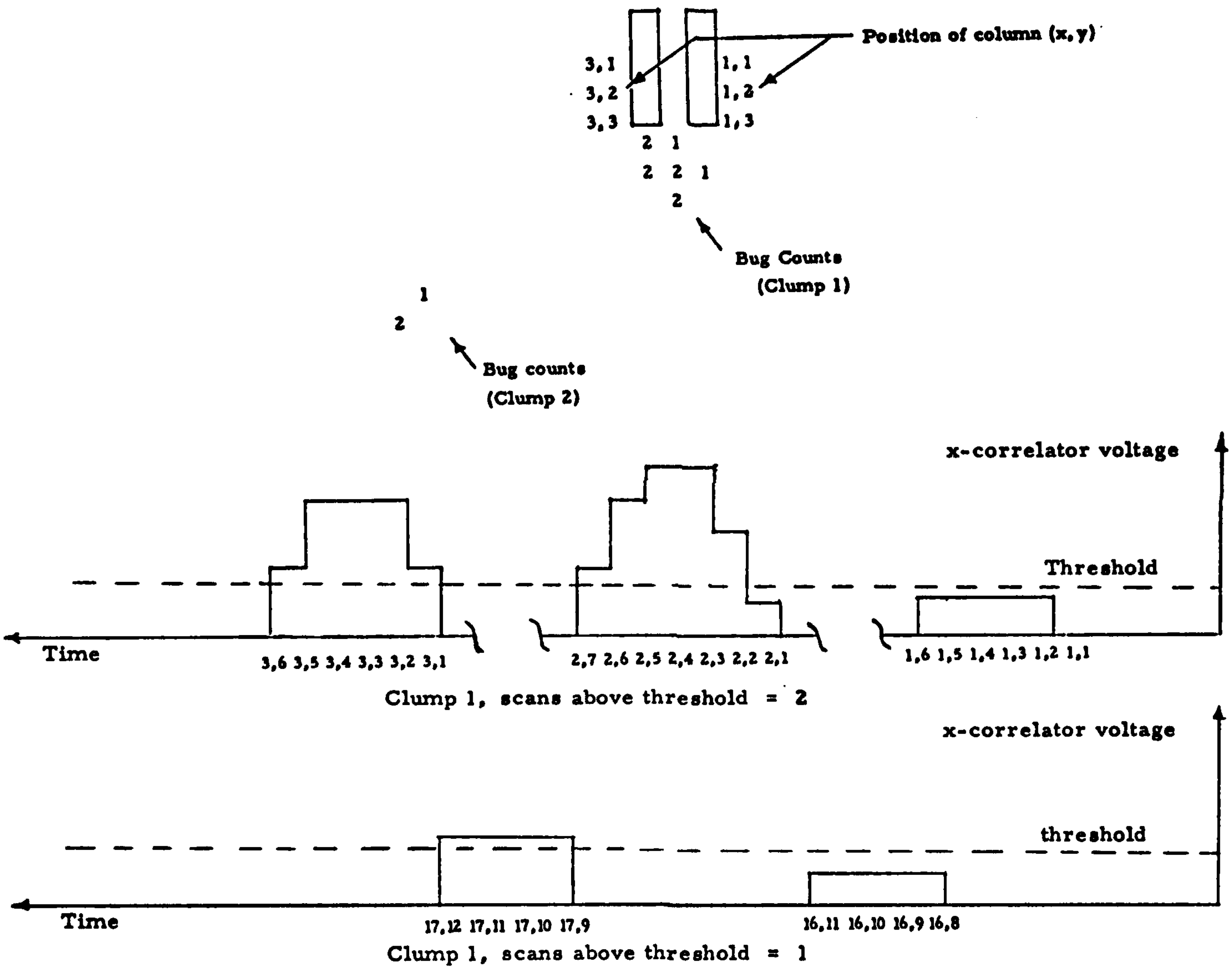


Figure 3-23 X-Correlator Profiles (Example)

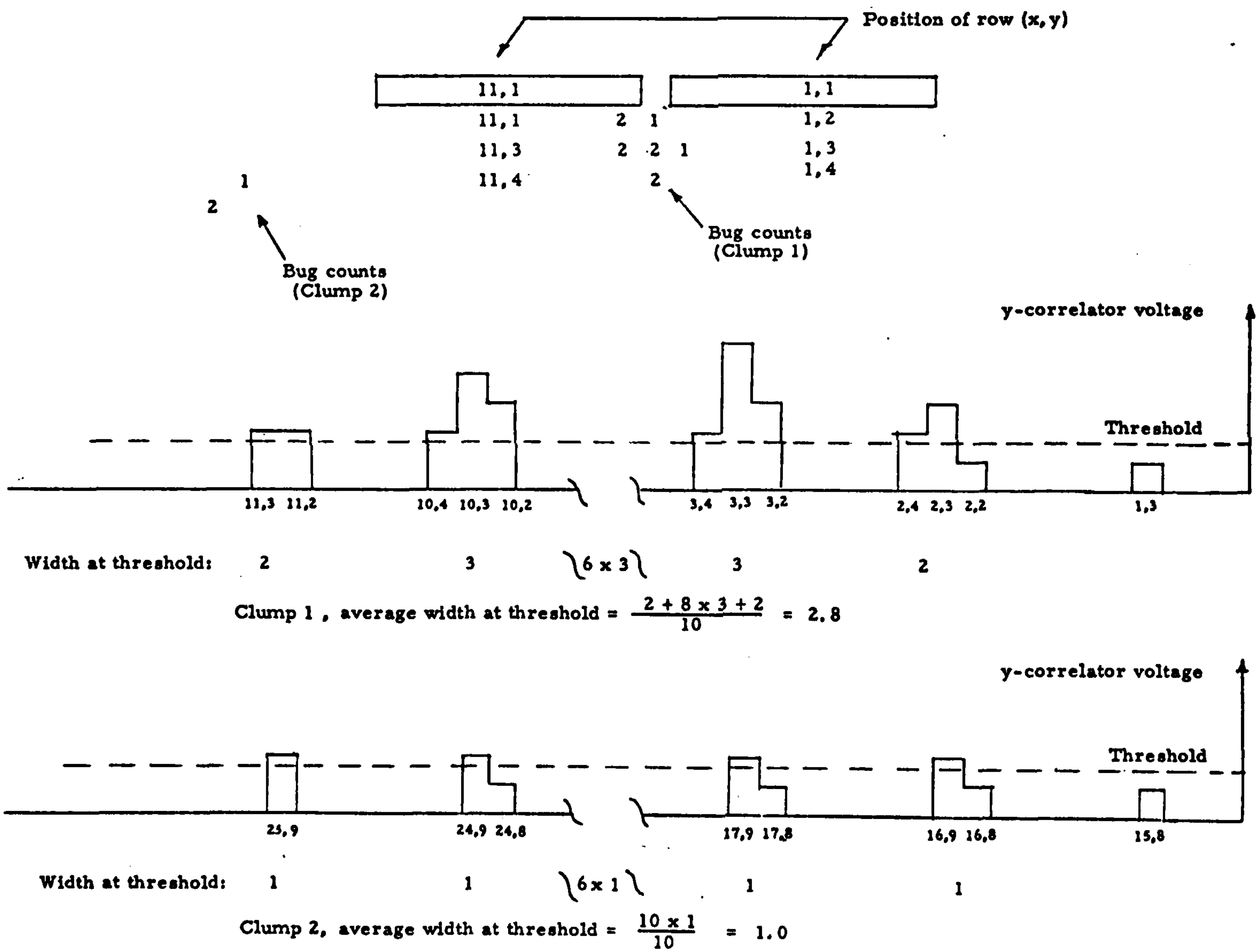


Figure 3-24 Y-Correlator Profiles (Example)

figures show the pertinent portion of the shift register (column for x and row for y) in two positions with position indices of the form (x, y) for reference with the waveforms.

Figure 3-25 shows the count distribution grid which is the format used for recording the data obtained using the circuits of Figure 3-22. During a run, the x counts are totalled up on one counter and the y counts on a second counter. Two charts are made up similar to the scheme shown in Figure 3-25 with one chart used to tabulate the x counts and the other to tabulate the y counts. A run is made for the various threshold combinations of V_t and V_h which give significant numbers of counts. These thresholds are incremented to correspond to correlator window elements on the abscissa (i.e. V_t) and to correlator counts on the ordinate (i.e. V_h). These latter designations also are indicated in Figure 3-25. For each pair of threshold settings used the resultant count is placed in the corresponding box, and this is done for both x and y. This number represents the number of occurrences during the run in question which exceed both thresholds and thus include not only the occurrences within the box in question but in all boxes above it and to the right of it as well. In order to find the number of counts C_{ab} within the box in question whose thresholds are V_{ta} and V_{hb}, that is the number of occurrences whose falling between V_{ta} and $V_{t\,(a+1)}$ in duration and between V_{hb} and $V_{h\,(b+1)}$ in amplitude, we use the relation

$$C_{ab} = R_{ab} - R_{a\,(b+1)} - R_{(a+1)b} + R_{(a+1)(b+1)},$$

where R is the reading obtained with thresholds V_{ta} and V_{hb}, etc.

An actual example of these calculations is shown in Figure 3-26 for wet Sm. At (a) the x-axis data is shown and the y-axis data at (b). The numbers appearing in the centers of the squares are the readings R_{ab} obtained from the counters with the counts C_{ab} occurring within the individual boxes appearing above the readings.

In order to compute the statistical profile data, the average number of correlator counts for each width is calculated. In other words the average height for each column for both x and y in Figure 3-26 is calculated using the relationship,

$$\bar{b}_a = \sum_{b=1}^{b_{max}} bC_{ab} \qquad (3\text{-}1)$$

where the notation is as defined above and in Figure 3-25. Equation (3-1) is evaluated for all significant values of a, and then it is weighed by the proportion of the total counts occurring in column a. The fraction of total counts in column a is simple

$$\frac{R_{a1} - R_{(a+1)1}}{R_{11}} .$$

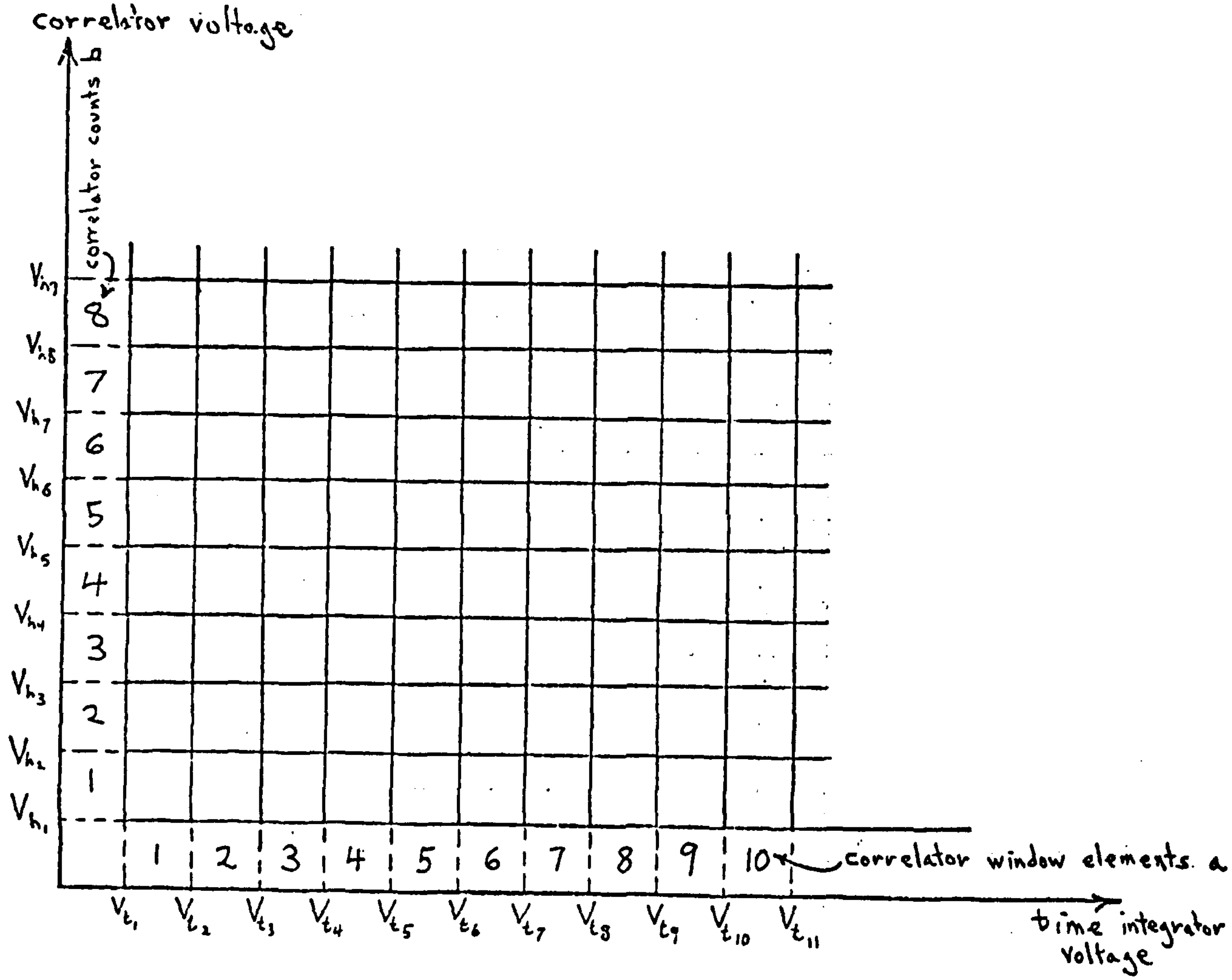
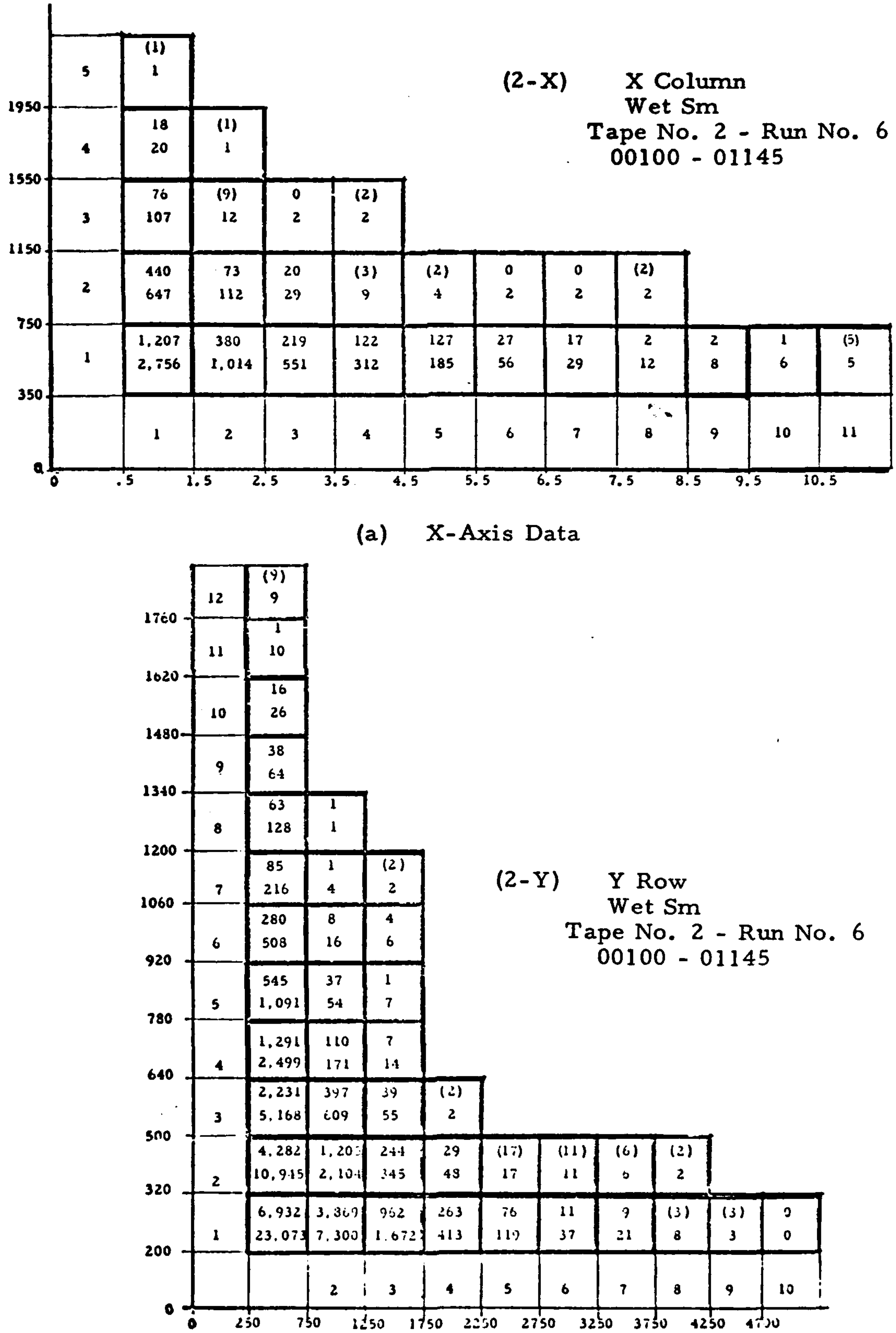


Figure 3-25 Correlator Count Distribution Grid



(a) X-Axis Data

(b) Y-Axis Data

Figure 3-26 Correlator Count Distribution Grid (Example of Wet Sm)

The resultant statistical profile p(a) is then

$$p(a) = \frac{R_{a1} - R_{(a+1)1}}{R_{11}} \bar{b}(a), \qquad (3\text{-}2)$$

which is evaluated for all values of all given significant values of p(a). Finally p(a) is normalized to p'(a) as follows:

$$p(a) = \frac{p(a)}{\left[\sum_{a=1}^{a_{max}} p(a)\right]}$$

Clump Density Distribution Plots:

The results of the analysis just described are plotted in Figures 3-27 to 3-37. In each figure, the x data appears on the left half-page and the y of the right. These accompanying charts show the clump density distributions for the agents indicated. The plots indicate the relative rates of occurrence of clumps of the indicated width a, weighted by the average height b_a at the width indicated. This average height is also noted numerically at each width interval. This latter information also is tabulated separately in Tables 3-2 and 3-3. The data is normalized as described in Equation (3-3) and expressed in percent. Unless noted otherwise the runs were made at Edgewood. The parameter $\bar{b}_a$ is indicated numerically above each corresponding element.

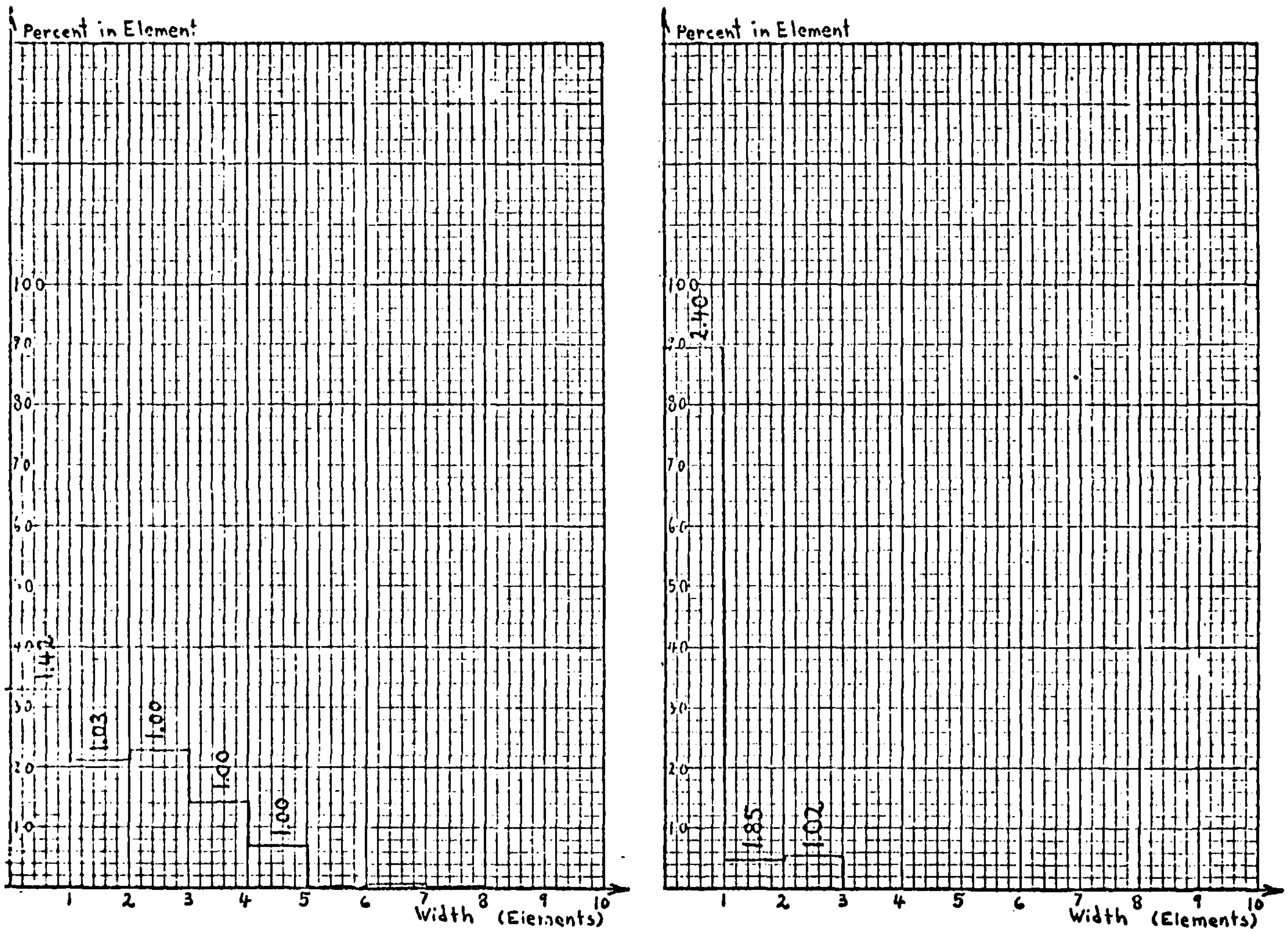


Figure 3-27 Wet Select Egg Clump Density Distribution

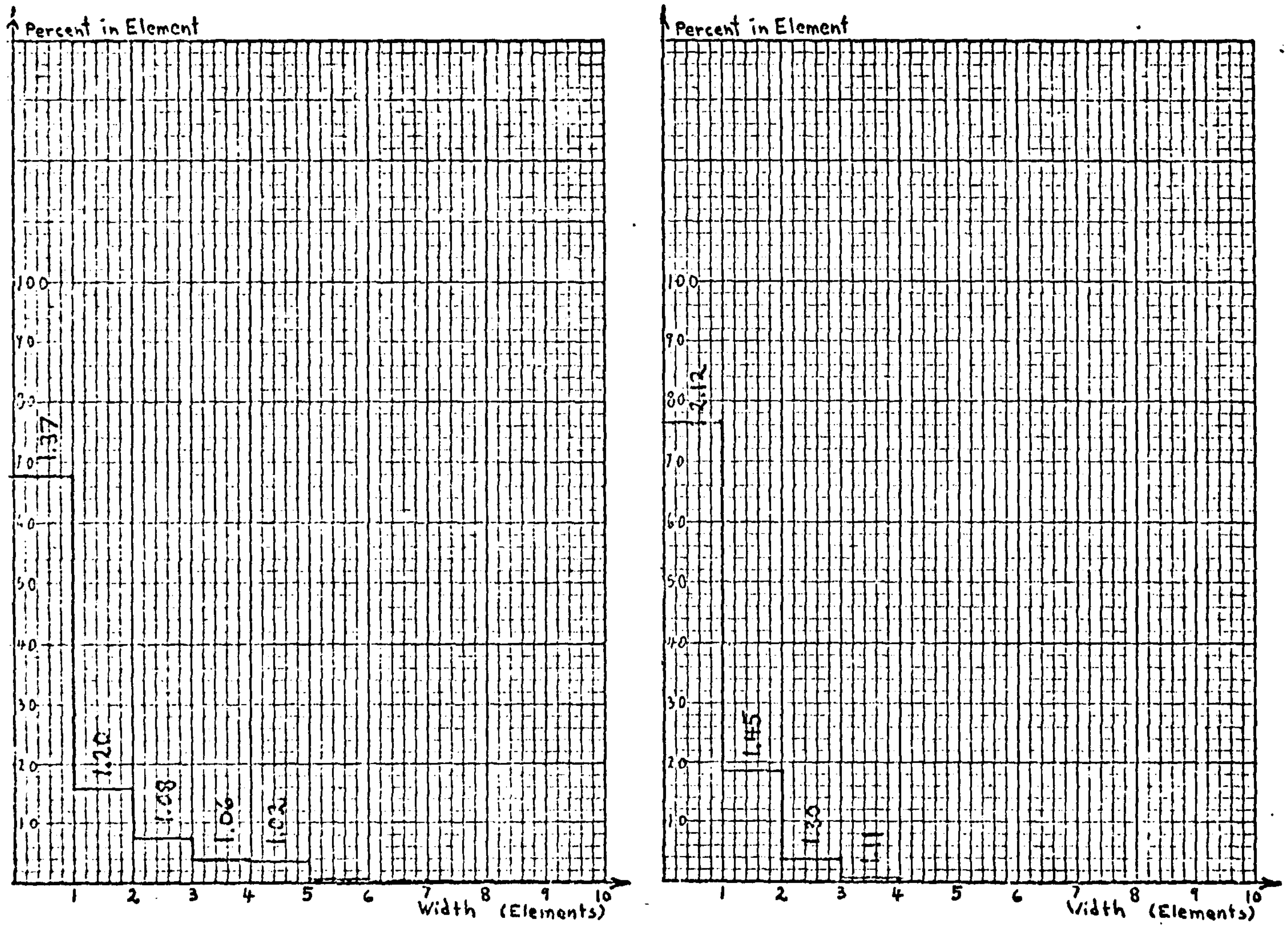


Figure 3-28 Wet Sm Clump Density Distribution

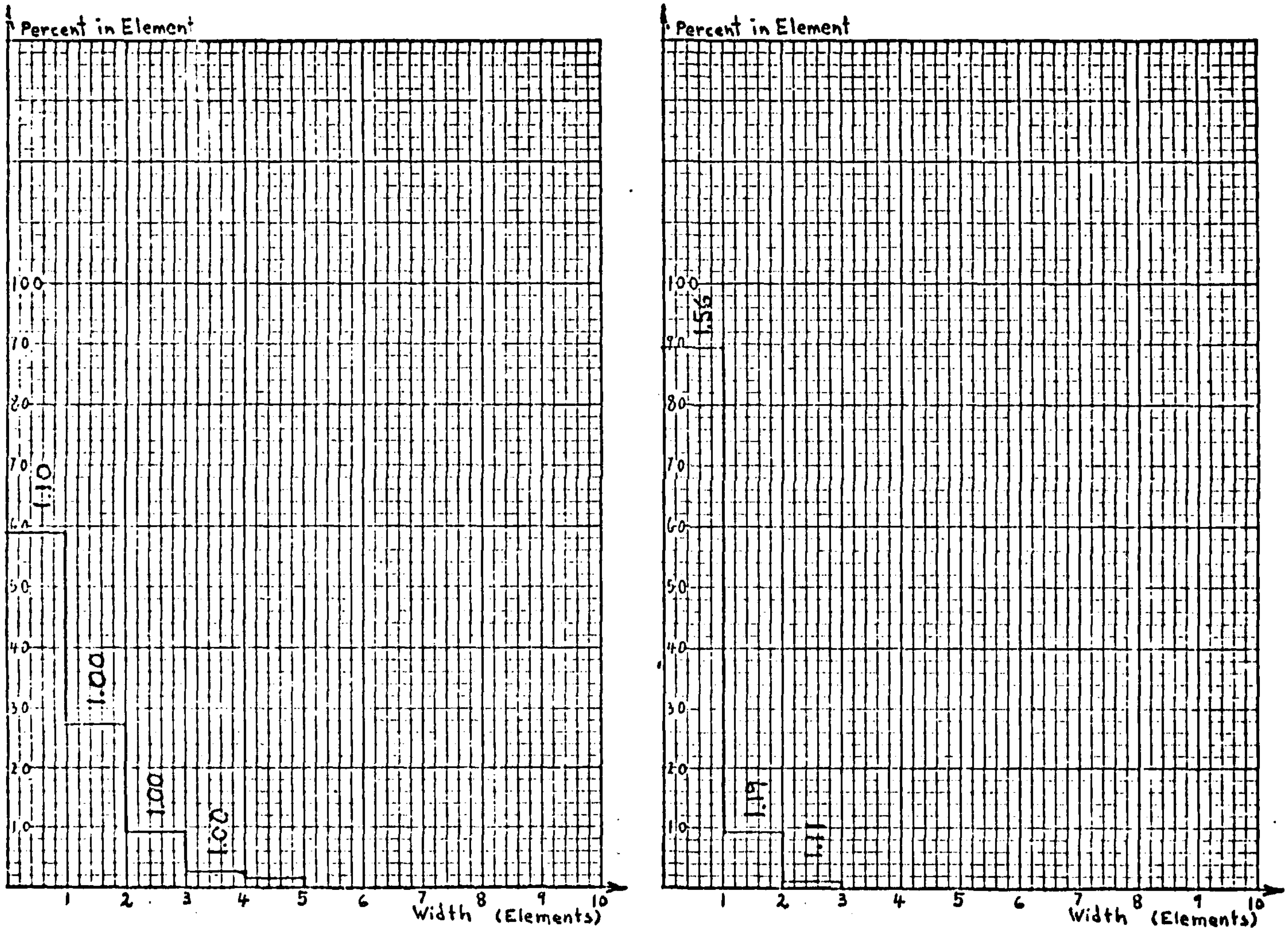


Figure 3-29 Edgewood Background Clump Density Distribution

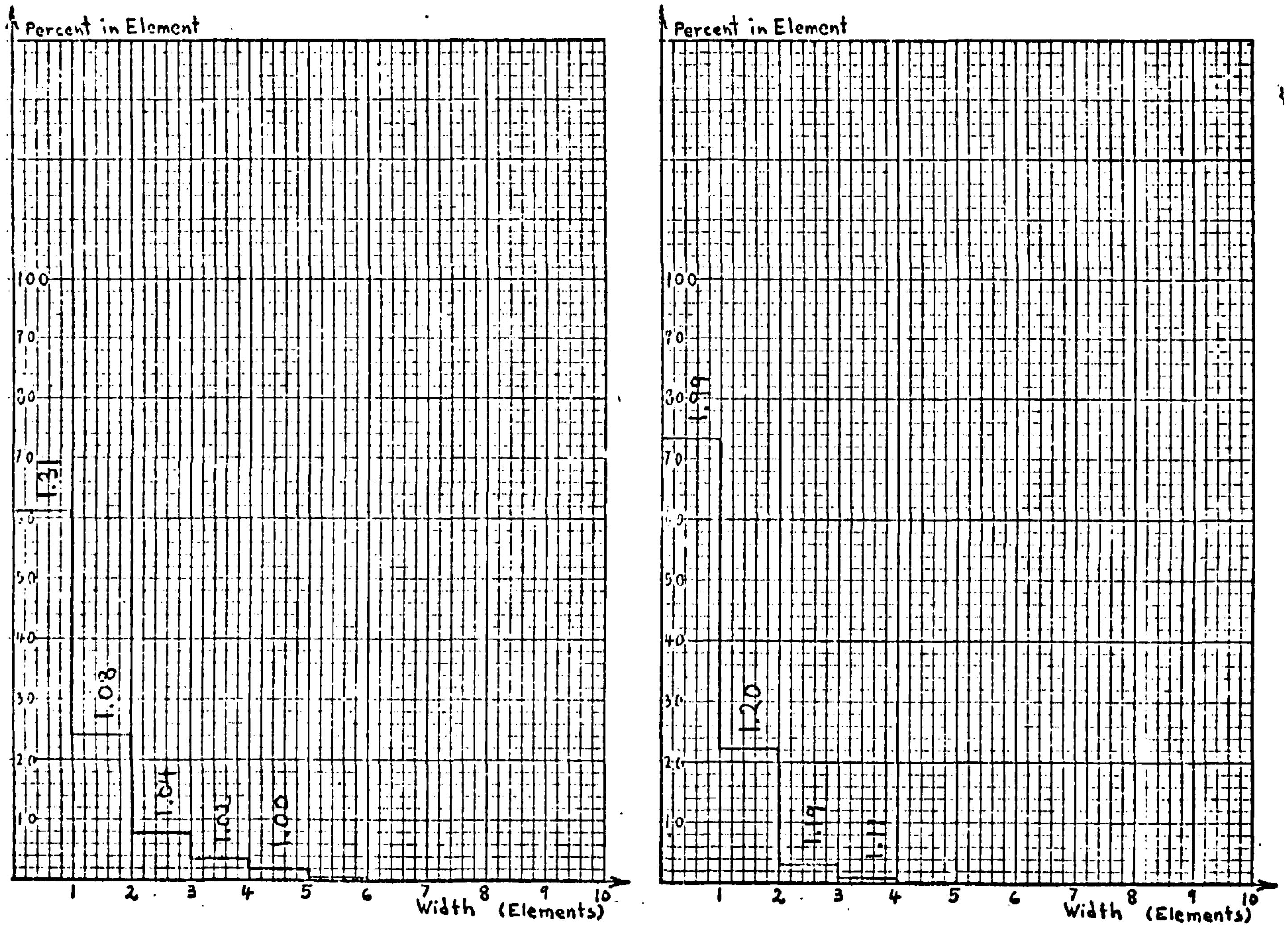


Figure 3-30 Wet Mold Spore Clump Density Distribution

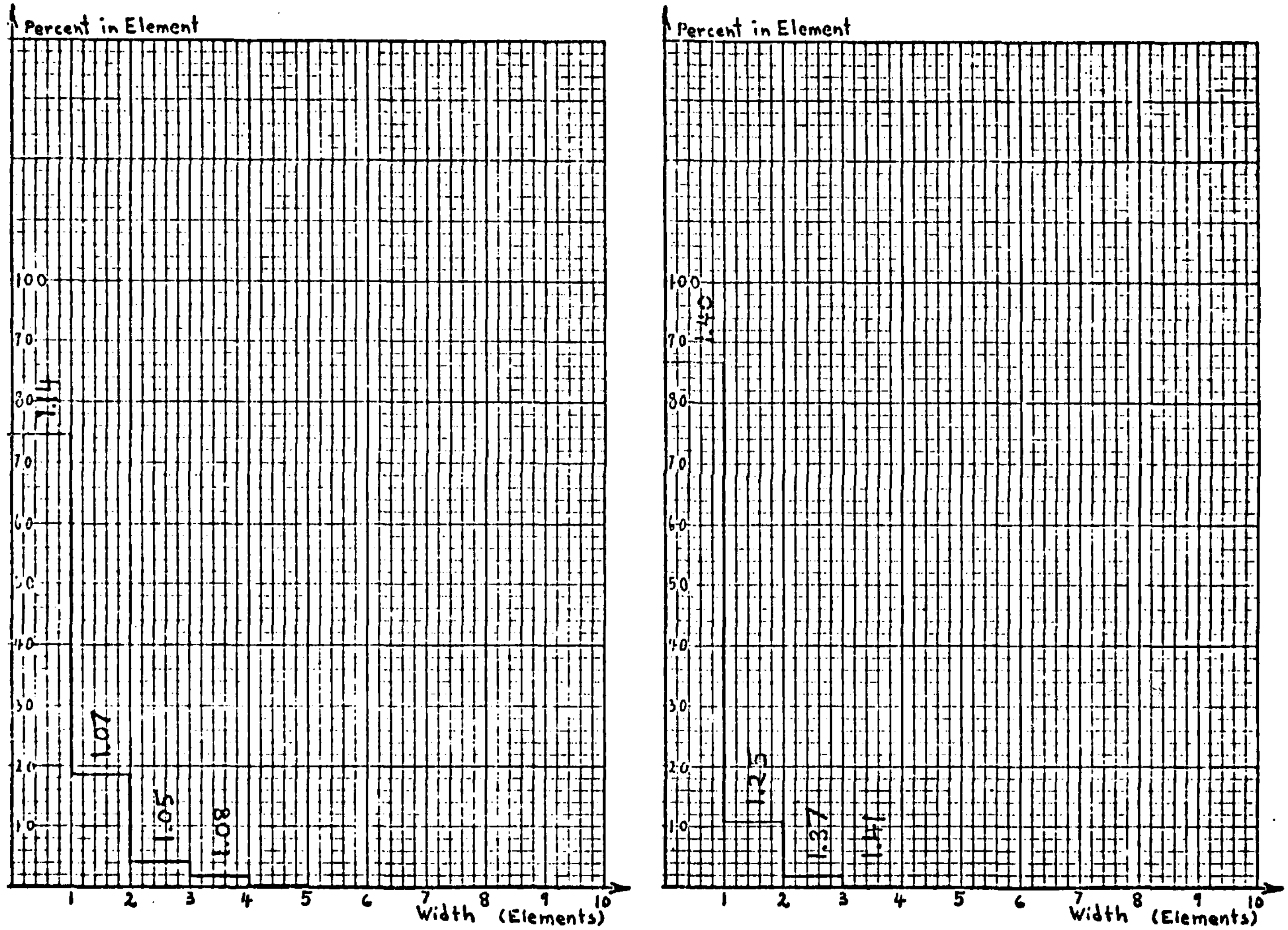


Figure 3-31 Dugway Background Clump Density Distribution

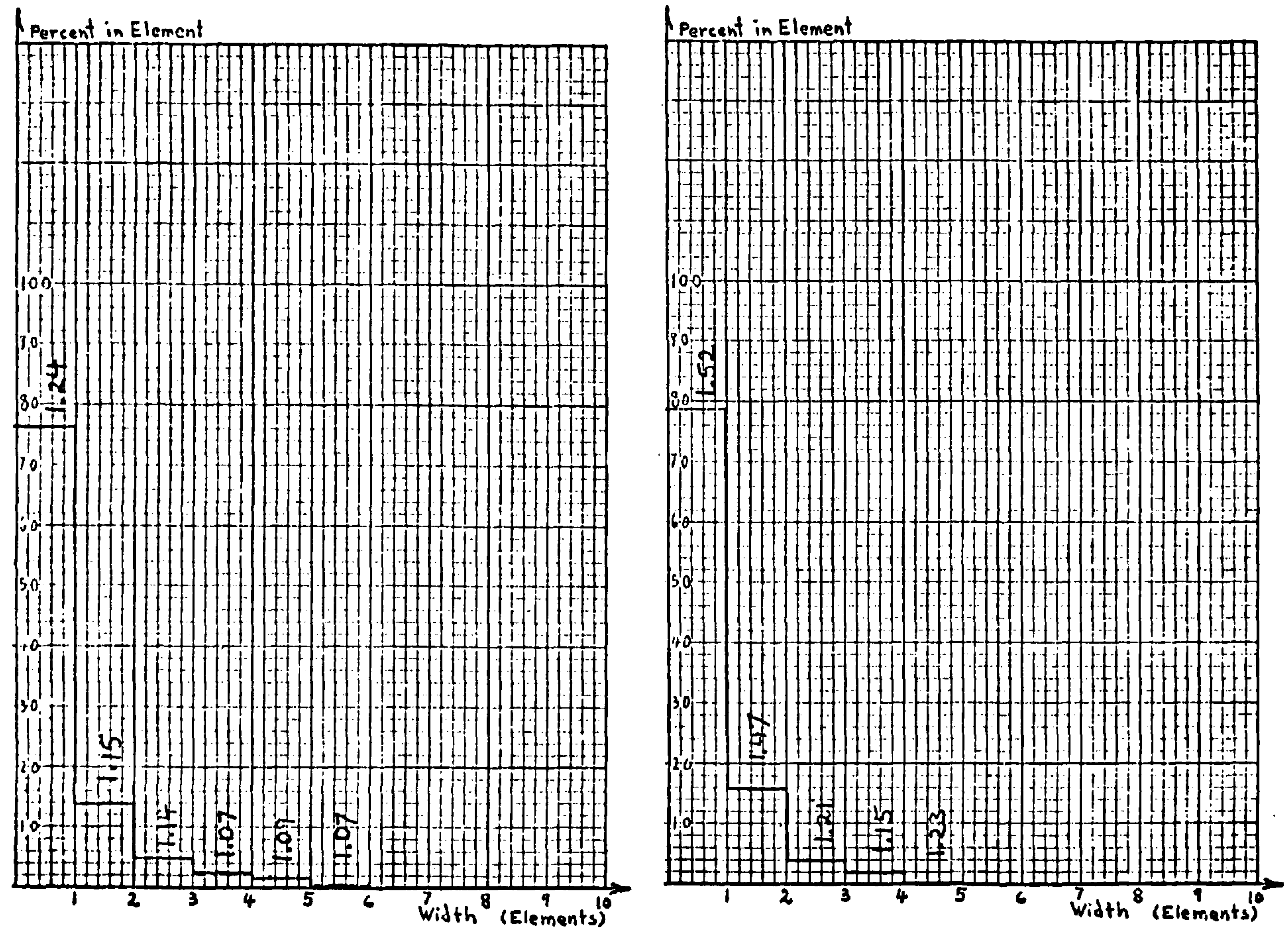


Figure 3-32 Wet Bg Background Clump Density Distribution

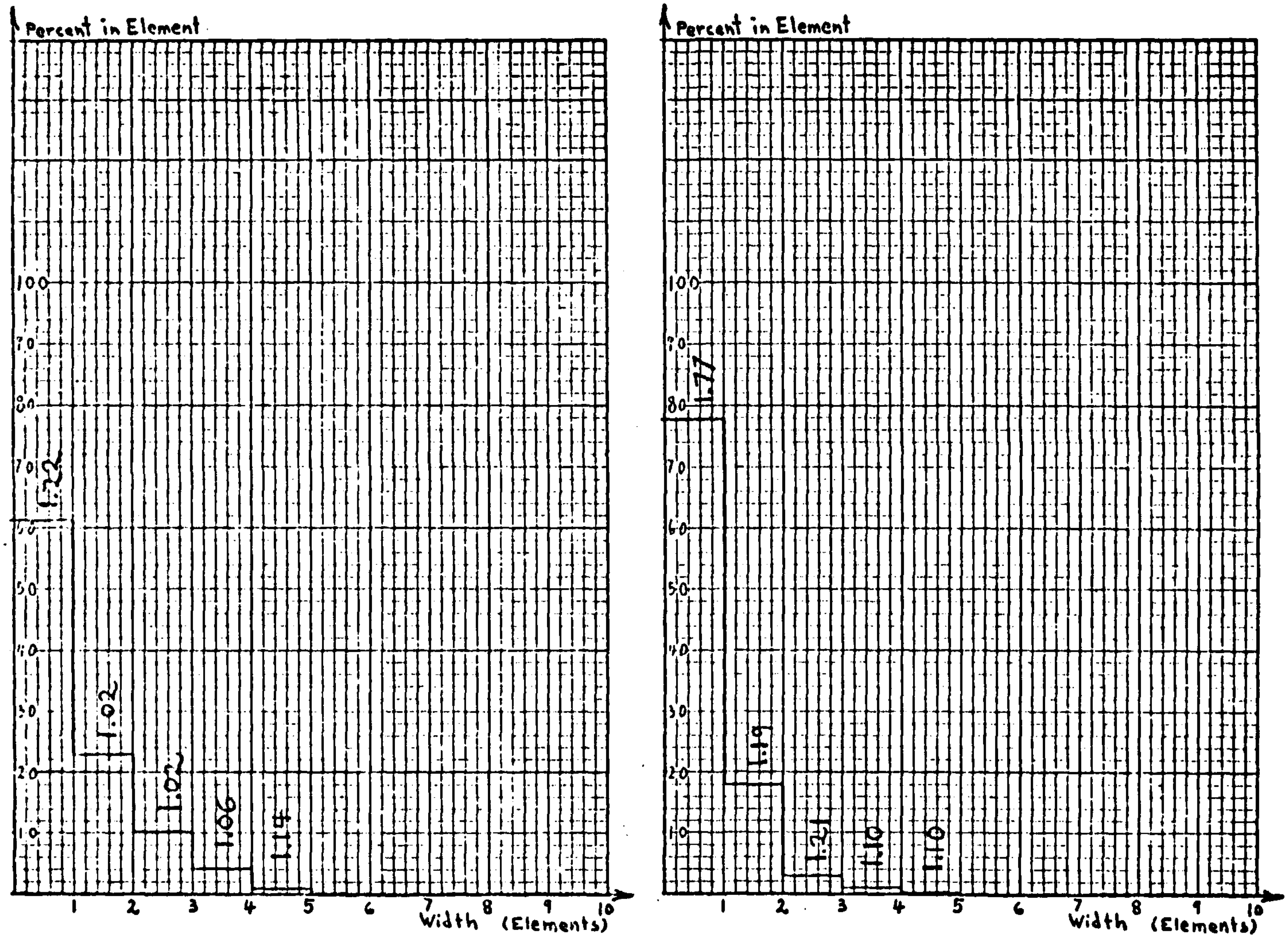


Figure 3-33 Dry Select Egg Clump Density Distribution

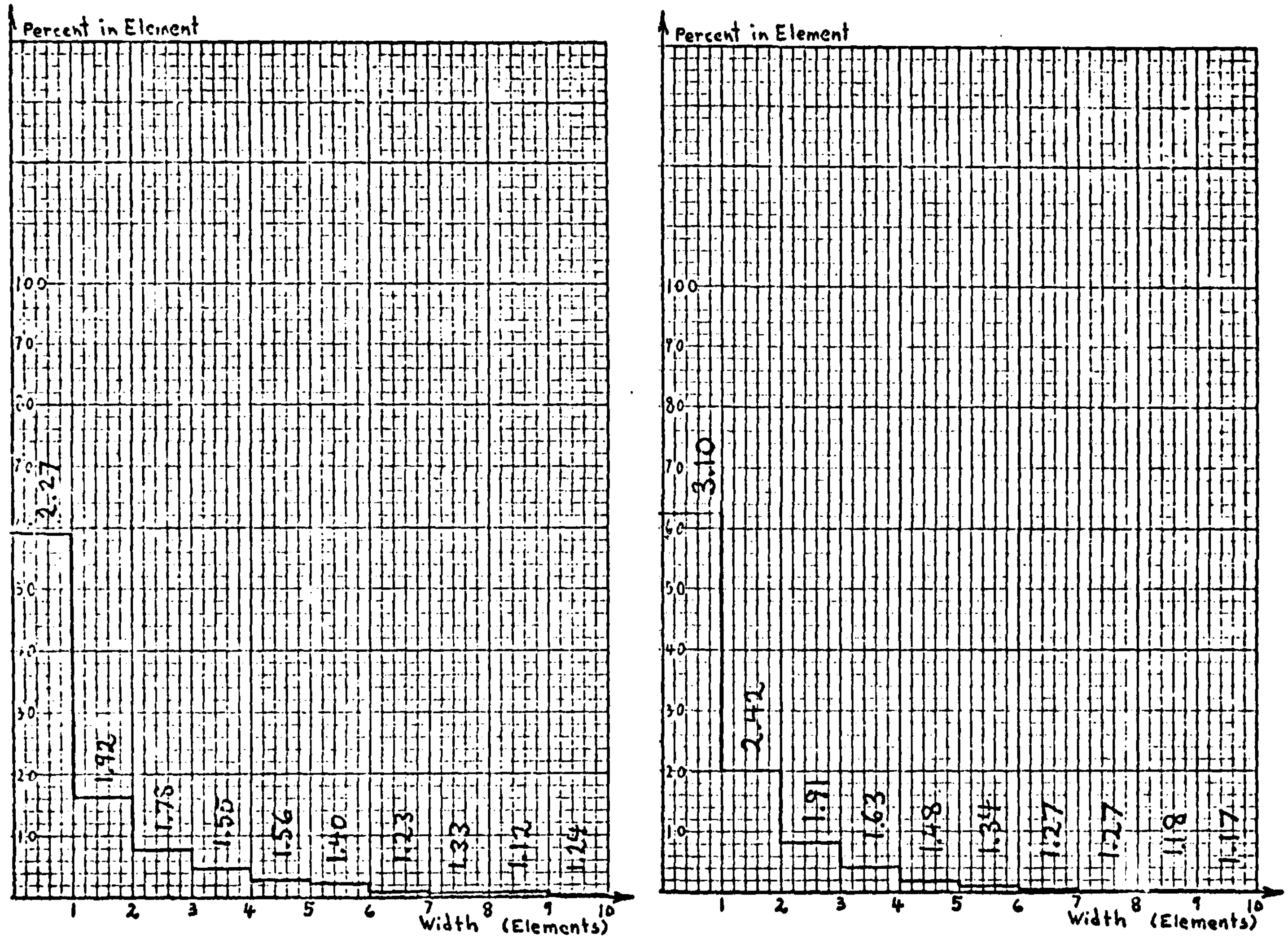


Figure 3-34 Dry Sm (Heavy Concentration) Clump Density Distribution

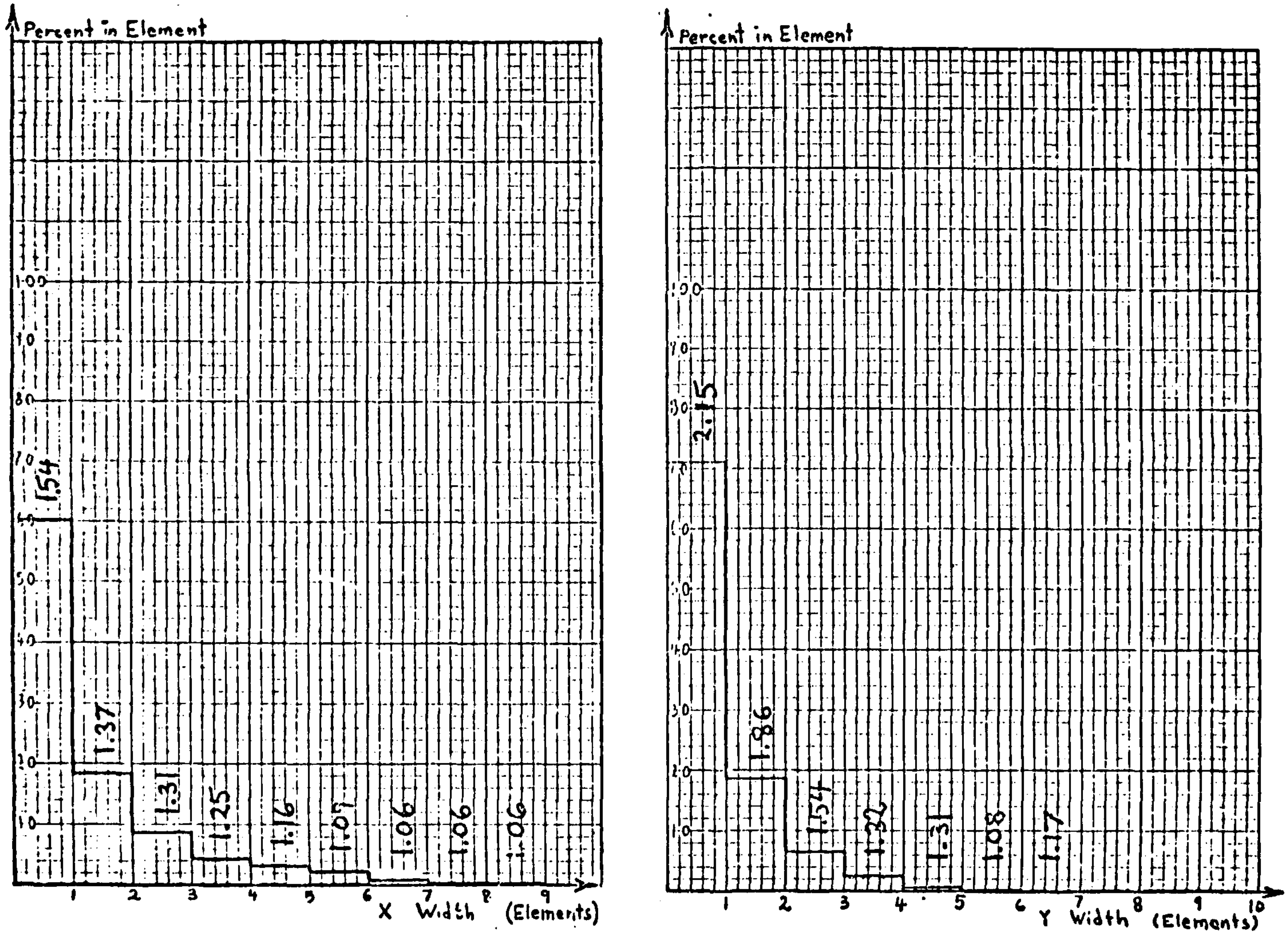


Figure 3-35 Dry Bg (Heavy Concentration) Clump Density Distribution

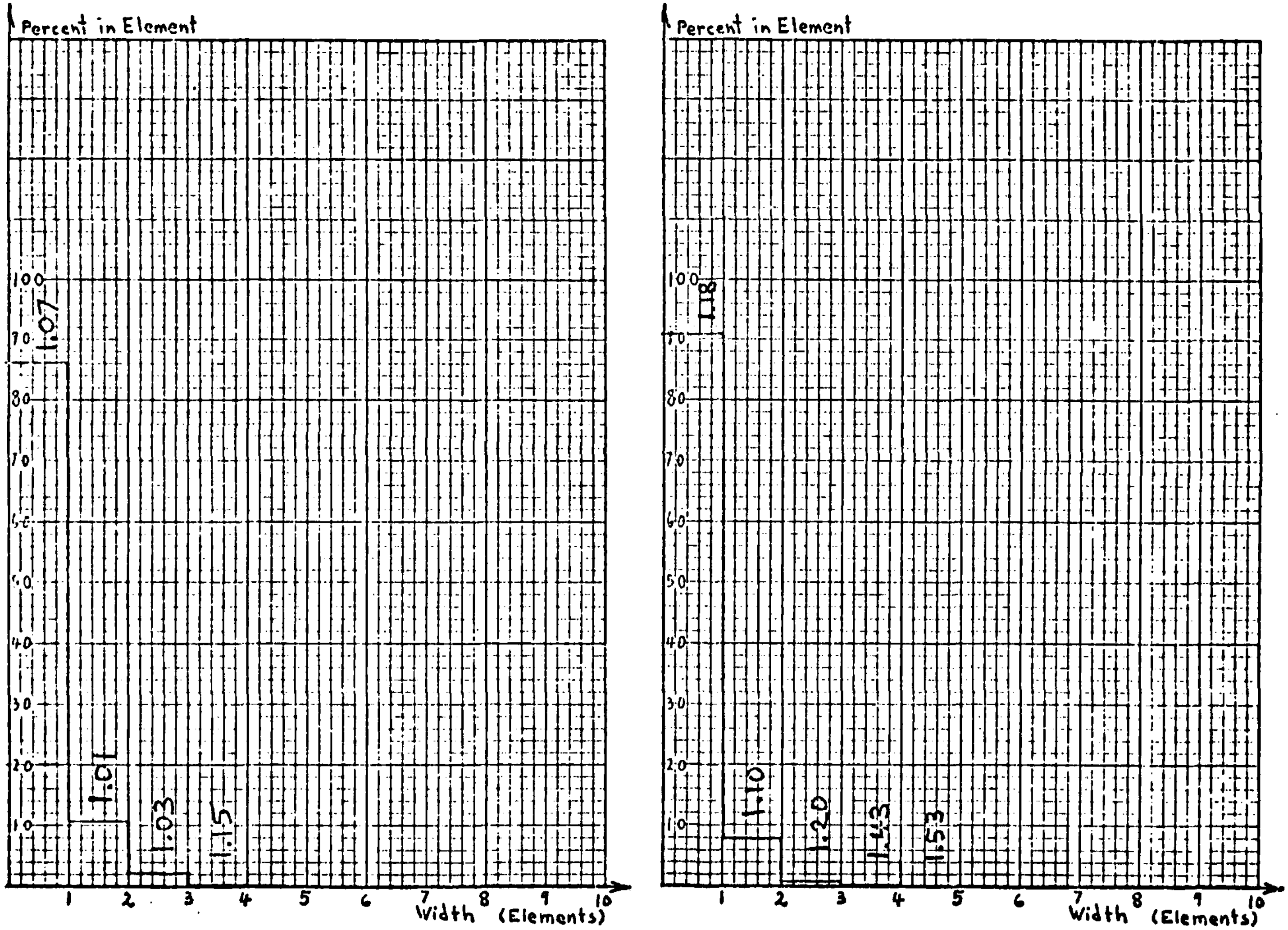


Figure 3-36 Wet Pt (Dugway Hot Test) Clump Density Distribution

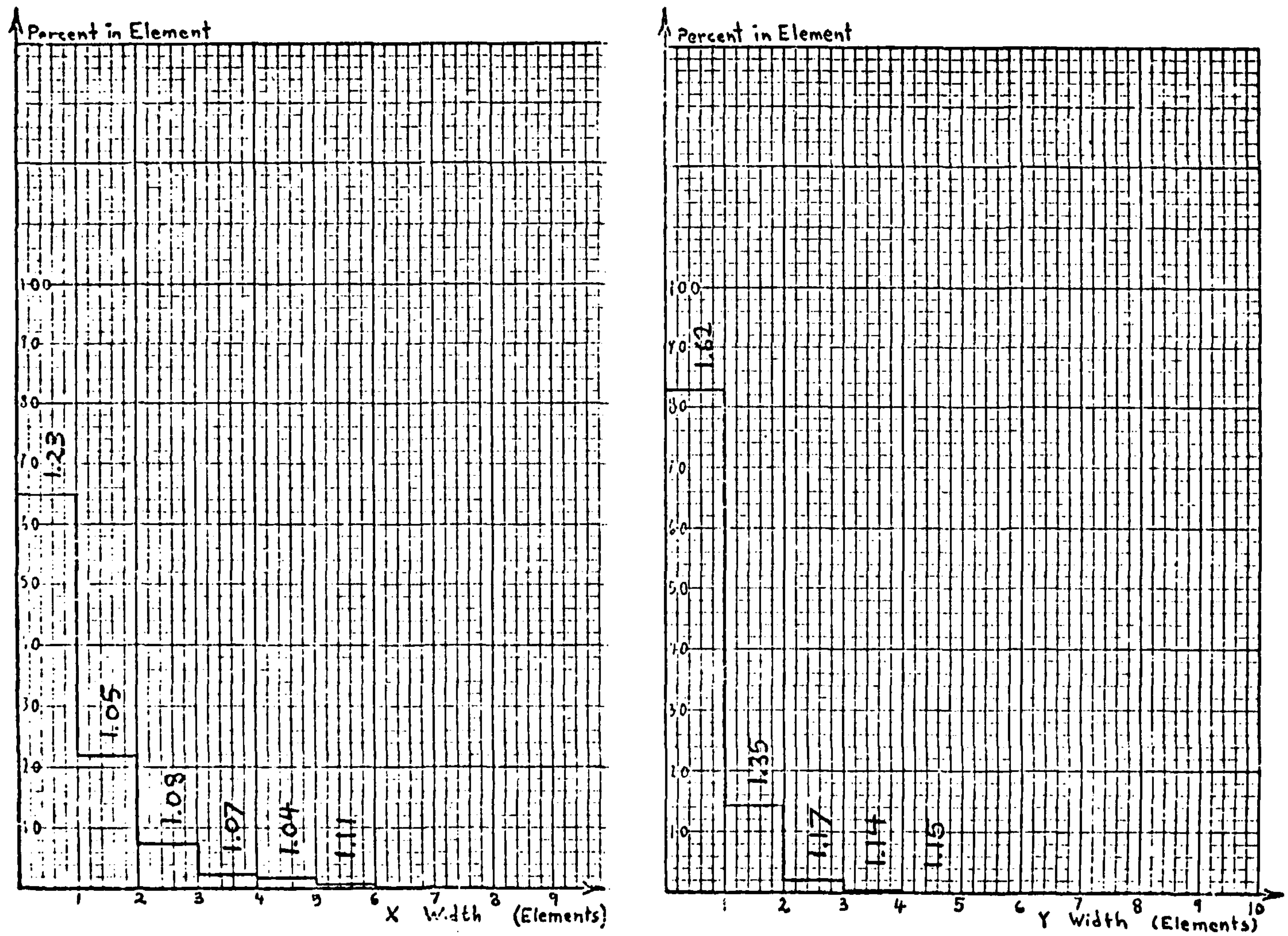


Figure 3-37 Q (Dugway Hot Test) Clump Density Distribution

TABLE 3-2 X HEIGHT AVERAGES

Width in Elements:

RUN:	1	2	3	4	5	6	7
Wet Select Egg	1.42	1.03	1.00	1.00	1.00	1.00	1.00
Wet Sm	1.37	1.20	1.08	1.06	1.02	1.00	1.00
Edgewood Background	1.10	1.00	1.00	1.00	1.00	1.00	--
Wet Mold Spore	1.31	1.08	1.04	1.02	1.00	1.00	1.00
Dugway Background	1.14	1.07	1.05	1.08	1.19	1.00	1.00
Wet Bg	1.24	1.15	1.14	1.07	1.09	1.07	1.00
Dry Select Egg	1.22	1.02	1.02	1.06	1.14	1.00	1.00
Dry Sm (heavy concentration)	2.27	1.92	1.78	1.55	1.56	1.40	1.23
Dry Bg	1.54	1.37	1.31	1.25	1.16	1.09	1.06
Pt (Dugway hot test)	1.07	1.01	1.03	1.15	1.00	2.00	--
Q (Dugway hot test)	1.23	1.05	1.08	1.07	1.04	1.11	1.00

TABLE 3-3 Y HEIGHT AVERAGES

	Width in Elements:						
	1	2	3	4	5	6	7
RUN:							
Wet Select Egg	2.40	1.85	1.02	1.14	--	--	--
Wet Sm	2.12	1.45	1.30	1.11	1.18	1.50	1.40
Edgewood Background	1.56	1.19	1.11	1.00	--	--	--
Wet Mold Spore	1.99	1.20	1.19	1.11	1.12	1.00	1.00
Dugway Background	1.40	1.25	1.37	1.41	1.06	1.58	1.00
Wet Bg	1.52	1.47	1.21	1.15	1.23	1.02	1.00
Dry Select Egg	1.77	1.19	1.21	1.10	1.10	2.00	1.56
Dry Sm (heavy concentration)	3.10	2.42	1.91	1.63	1.48	1.34	1.27
Dry Bg	2.15	1.86	1.54	1.32	1.31	1.08	1.17
Pt (Dugway hot test)	1.18	1.10	1.20	1.43	1.53	--	--
Q (Dugway hot test)	1.62	1.35	1.17	1.14	1.15	1.00	--

4.0 HARDWARE DESIGN AND FABRICATION

The hardware portion of this contract involved the modification of one previously existing subsystem and the design, fabrication, installation and testing of two new electronic subsystems. Specifically these three items are as follows:

- Modify the existing Pattern Recognition Correlator to optimize the design.
- Design and build an alarm logic system.
- Refine current pattern recognition electronics to facilitate a more effective ability to distinquish between egg agents and spurious mold spores (Mold Spore Detector).

Since two identical pattern recognition systems had been built on the earlier contract, this program called for the fabrication of two duplicates of each new piece of hardware. In the case of the correlator modifications (first item above), these modifications were performed by Organon Diagnostics to the one pattern recognition system furnished for the project on a government-furnished equipment basis, with instructions being supplied to the customer for modifying the other unit. In addition, the program extension called for fabrication of the following items:

- One duplicate of each type of plug-in card in the card cage assembly
- One duplicate alarm logic system

4.1 Modification of Existing Correlator

The first hardware task listed above involved the modification of the existing Pattern Recognition Correlator to upgrade the design on the basis of performance test data, etc. Basically this correlator subsystem developed by Organon Diagnostics under the previous contract (Contract No. DAAA 15-72-C-0375) is a system which retains in a shift register memory, patterns scanned by the PACT microscope during the last several (originally ten) scan lines, and computes the profiles of these patterns in a direction parallel to the tape direction and transverse to it. The system cross-correlates these two profiles with internal patterns, determined by the values of fixed resistors and the two resultant outputs are fed to threshold detectors to provide a "yes or no" result from the correlator. Originally, automatic gain control (AGC) was employed ahead of the threshold detectors to make the correlator insensitive to the amplitude of the objects being scanned but rather sensitive only to their shape. For a complete discussion of this correlator, its theory and design, the reader is referred to the final report[1] issued on the preceding contract where it is referred to as the Approach 4 system. However, many of the principles of this correlator were discussed under the preceding section dealing with its predecessor, the Approach 3 system which was expanded into the later configuration.

[1] Final Report No. 1107F, 27 September 1974, Sections 4.3 and 4.4, pp. 4-21 through 4-39.

With regard to the effect of the AGC on the correlator, it was observed in analyzing the data that the average correlator output signal amplitude for the "average" agent will be greater than the "average" background. For this reason, any attempt to make the correlator insensitive to this parameter, i.e. the number of counts in the clump, would only degrade the performance of the correlator. For this reason the AGC function in the correlator has been deleted. This modification was made simply by removing the six VCR's Q1 through Q6 on card 15 in the correlator and replacing them with 650 ohm resistances. The 650 ohm values were obtained by connecting parallel pairs of 1.3 K resistors.

The orginal configuration of the correlator employed a shift register which contained four elements in the direction transverse to the tape (designated as the y-direction) and ten elements corresponding to ten scan lines down the tape (the x-direction) (see Figure 4-1). The y-axis correlator would generate cross correlation waveforms in conjunction with the four y-axis elements, while the x-correlation would be performed through ten scan lines. Later analysis indicated, however, that while the four elements represented good width for the correlator "window", the ten elements in the x-direction was considerably more than was required and that this number could be halved to five elements with essentially no loss of performance, thereby effecting a significant saving in circuit IC's and connections which could be especially valuable in future miniaturized versions of such a system. The adequacy of five scan lines can be seen from inspection of the data for the x-profiles in Figures 3-17 through 3-26 of this report. Here it is seen that there is very little contribution to the profiles beyond five elements.

This modification was implemented very easily through the removal of eight IC's from the Segment Summing and Storage Circuit (Card 17) which is shown in schematic form in Figure 4-2. Here the deleted IC's are M9, M11, M13, M15, M17, M19, M21 and M23. Of course, further simplifications can be made in future versions of the correlator, since the associated wiring connections can be eliminated also. After the IC's are removed, appropriate changes are required in the selection of values for the five remaining resistors which determine the correlator profile shape. However, the selection of these resistor values for both the x and y directions has been dealt with at length during this program.

The selection of optimum correlator resistor values for the x and y correlators was studied carefully on the basis of the agent and background profile data which are presented in Section 3 of this report. Initially, an approach which maximized the correlator output amplitude differences between agent and background inputs was considered. In other words, a method which determined the relative resistor values for the x and y correlators was employed which provided the largest agent-to-background amplitude ratio at the output of the correlator for an "average" agent and "average" background. The "average" agent characteristics were obtained by averaging the clump characteristics of eight selected agents, and the "average" background was obtained by averaging the same characteristics for the two backgrounds (Dugway and Edgewood).

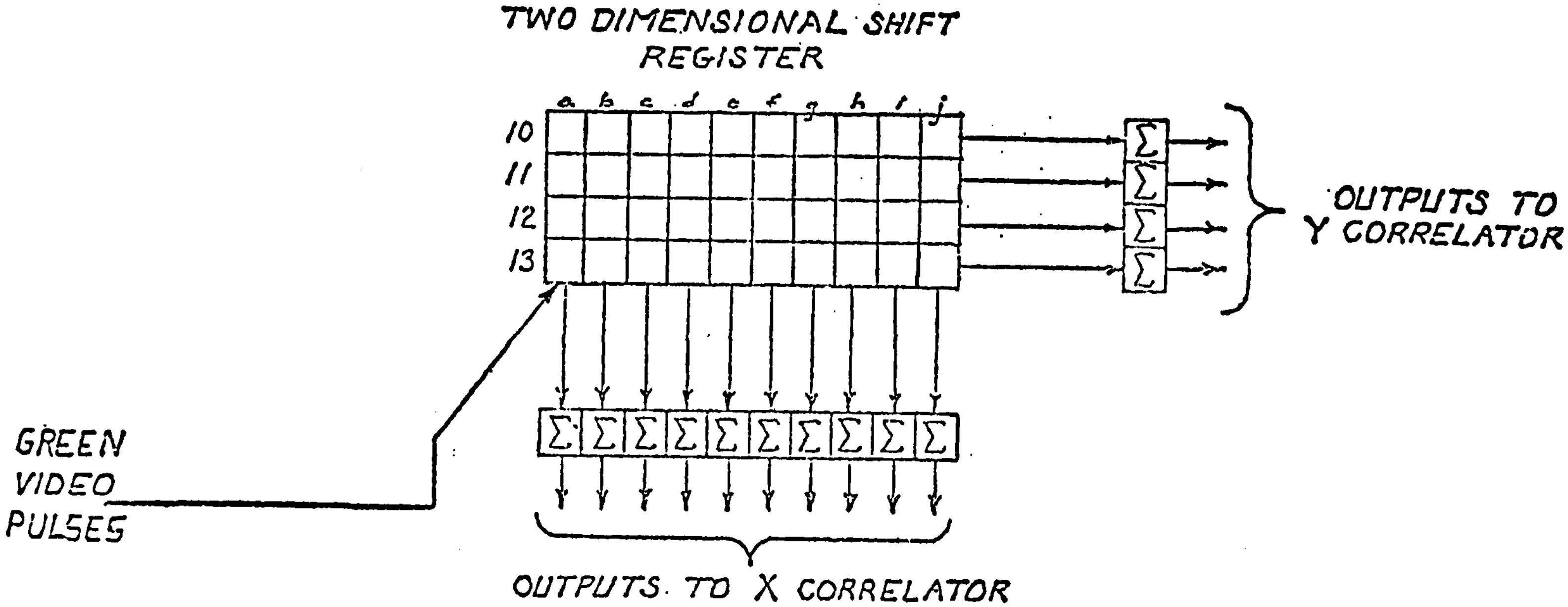


Figure 4-1 Shift Register and Segment Summing (Former Configuration)

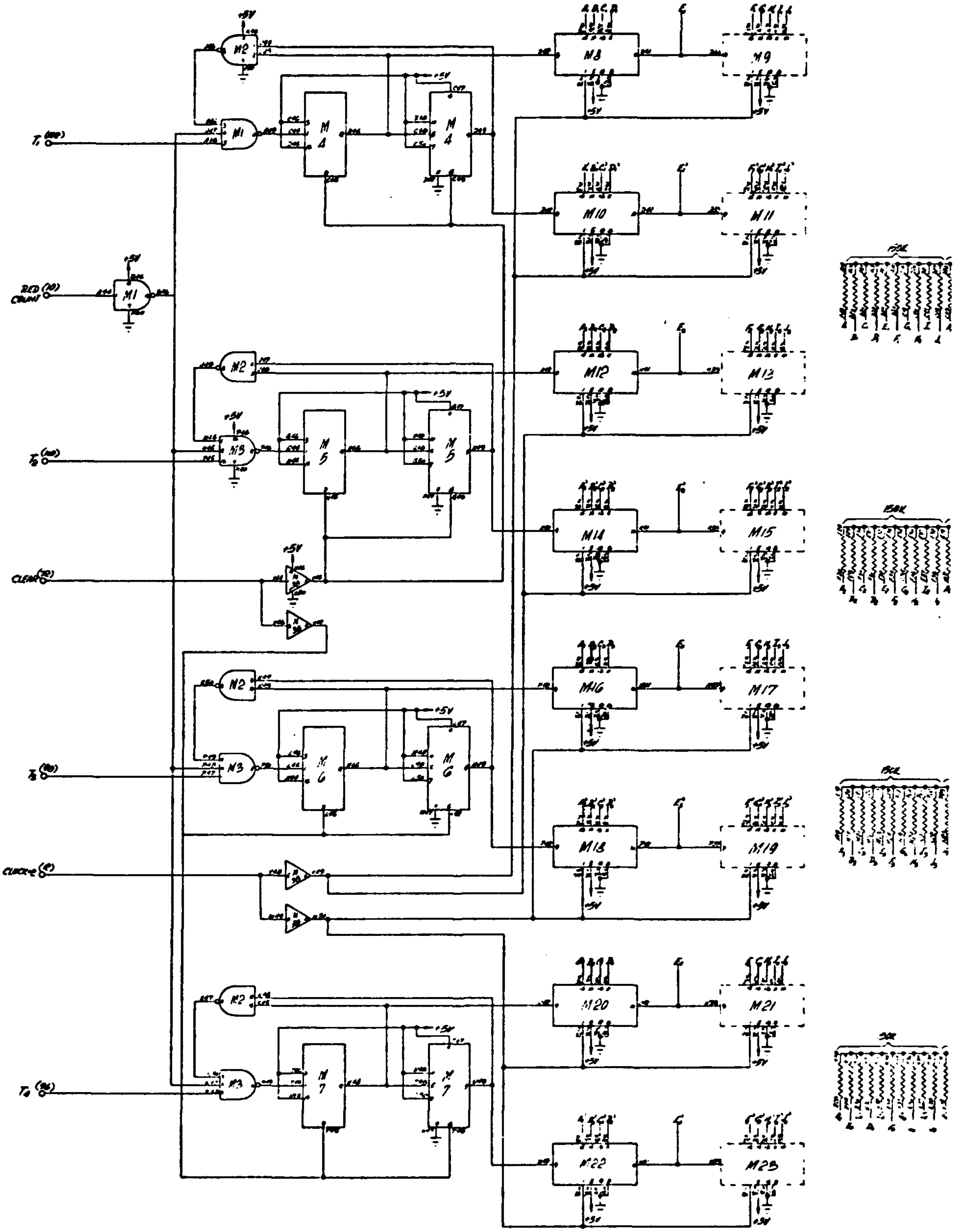


Figure 4-2 Portion of Correlator Card 17 Schematic With Deleted IC's (Dotted)

Further consideration of the problem of enhancing the performance of the correlator has led to the selection of a dual-profile scheme for either axis, whereby two sets of correlator resistors are used. One set of resistors has one distribution of resistors which weights particle counts in the central part of the window equally with those at the edges, while the other distribution weights the edges of the window most heavily. This is done for the x and y axis; thus either axis has two sets of resistors, one set favoring the center and one set favoring the edges. Each pair of x and y resistor sets is summed and fed to a threshold detector. The two detector outputs then are fed into an AND gate (refer to Figure 4-3).

The rationale for this new approach is to use the normal resistor grouping favoring the center to provide normal correlation action, while allowing the grouping favoring the edges to reject particles and clumps which are of a relatively small size. The data obtained in the pulse group analysis (clump density distribution) indicates that this parameter is rather sensitive in its ability to distinguish between background and agent.

A block diagram of the modified correlator is shown in Figure 4-3. All of the modifications are made on Card 15 (X and Y Correlator and Threshold) by taking advantage of unused functions and components.

4.2 Alarm Logic System

The Alarm Logic System is one of two new components designed, developed and added to the pattern recognition system on the present contract. Its purpose is to accept the data coming from various portions of the pattern recognition system and to analyze the data according to specific built-in algorithms and to present a simple "yes-no" indication to the operator concerning the presence of an alarm.

A block diagram showing the basic operation of the Alarm Logic System appears in Figure 4-4. Here the Alarm Logic System is shown monitoring the four channels of data which are supplied to it from the pattern recognition electronics. These channels are:

- Small red counts C_s.
- Large red counts C_L.
- Correlator counts C_p.
- Total counts C_t.

The counts C_s and C_L are supplied from the Mold Spore Detector where they assist in "weeding out" spurious red channel signals such as mold spores. The C_p counts are from the output of the correlator and the total counts C_t are obtained from the Improved Resolution Detector (green/red ratio detector). Each of these four channels of information is supplied to two averages; one of the averagers is a long-term averager (320 seconds) and the other is a short-term averager (80 seconds) with the approximate average values for these counts being computed since an exact computation would require substantially more circuitry. The approximation is made by assuming that the number of counts to be deleted during the updating of the averager is

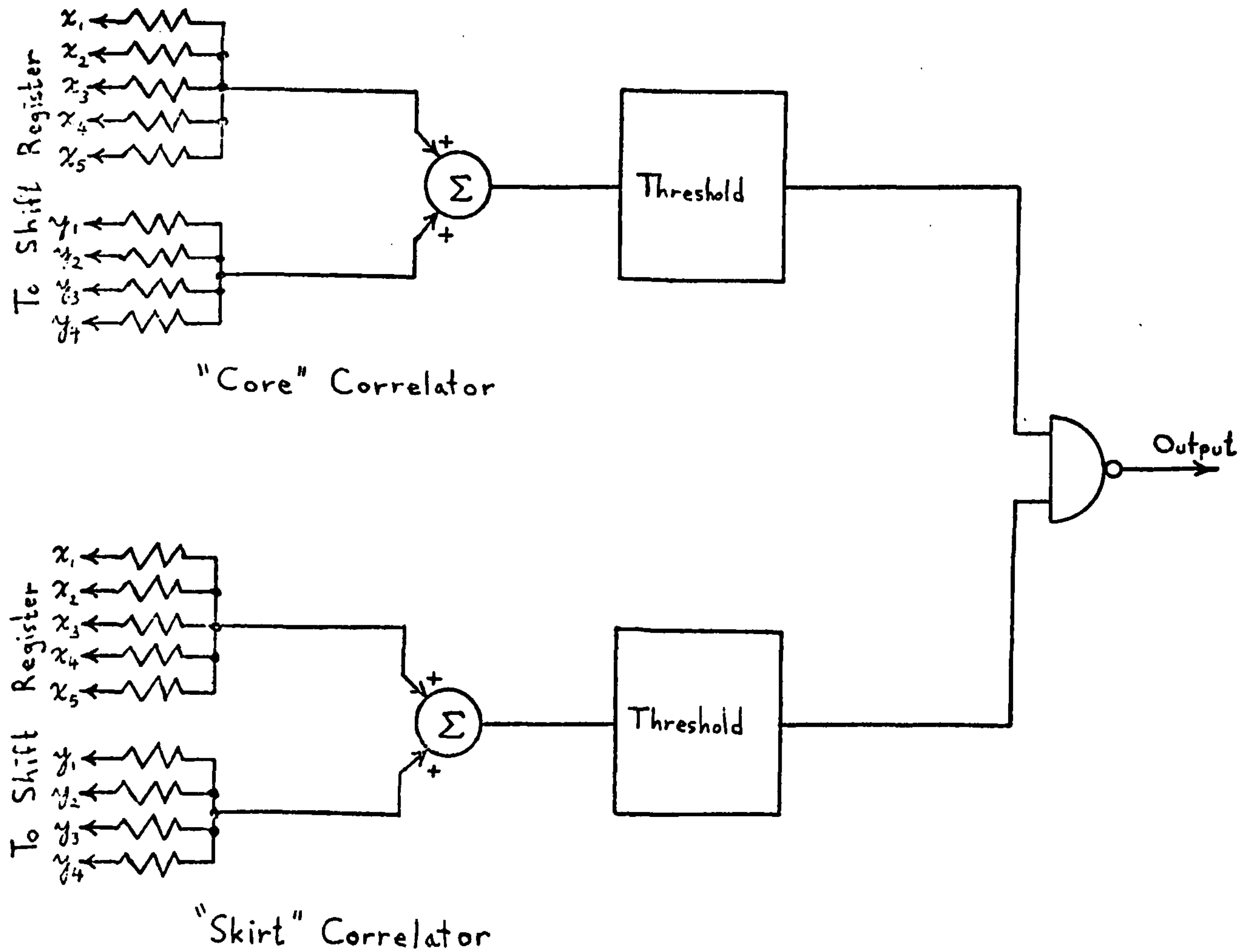


Figure 4-3 Simplified Functional Block Diagram of Modified Correlator

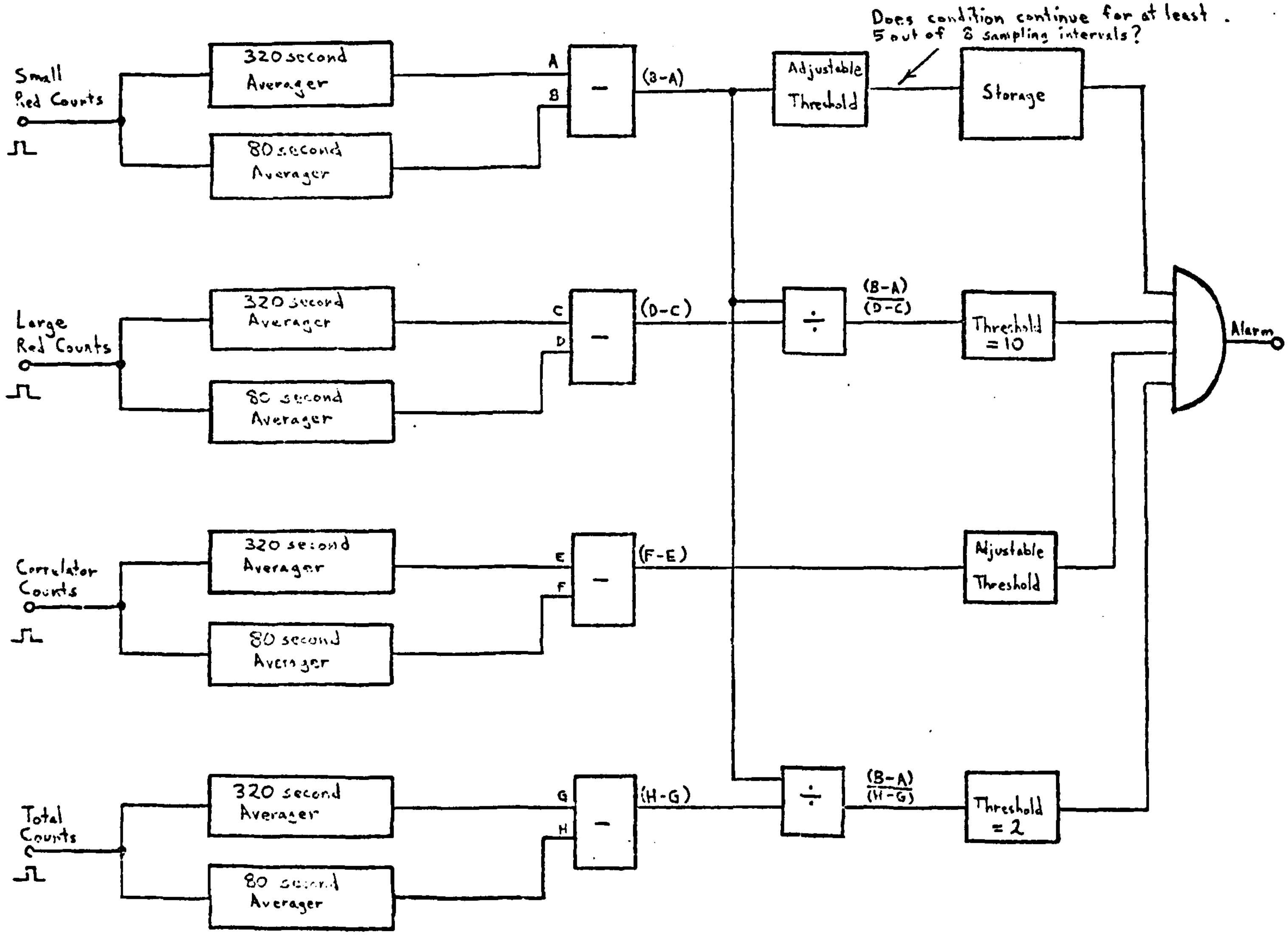


Figure 4-4 Alarm Logic System Block Diagram

equal to the number of counts in the averager at that time divided by the number of sampling intervals over which the averager is supposed to be working. This number is either 32 or 8 depending on whether the averager is the 320-second or the 80-second type, since the sampling interval is 10 seconds.

On each of the four channels, the short-term average is subtracted from the long-term average. These differences will be positive if the counts have been increasing in such a manner that the average during the shorter 80-second period is greater. These four differences are then fed to logic which requires the following conditions to be fulfilled:

- The small red count increase must exceed a set threshold value for at least 5 out of 7 sampling intervals.
- The small red count increase (i.e. difference) must be at least 10 times the large red count increase.
- The correlator counts must exceed a threshold value.
- The small red count increase must be at least one half the total count increase.

When all of these conditions have been satisfied, an alarm condition is indicated.

Detailed schematics of the Alarm Logic System appear in Figures 4-5 through 4-9. Figure 4-5 shows the timing circuit and the remaining Figures show the four averagers in detail. The entire Alarm Logic System is constructed on one large Augat board with 5 subsections. This board has been mounted in a standard configuration for rack mounting along with the Card Cage which contains the remainder of the Pattern Recognition System including the new Mold Spore Detector. Figures 4-10 through 4-13 show the Alarm Logic System viewed from four different angles. Figure 4-14 shows the Alarm Logic System and the Card Cage together.

4.3 Mold Spore Detector

The objective third task of the program has been the refining of the pattern recognition electronics to enhance its ability to reject mold spores while retaining the ability to accept egg signals. This has led to the development of an additional subsystem designated as the Mold Spore Detector.

Initial laboratory tests were conducted for the purpose of evaluating the feasibility of an approach which would distinguish between egg and mold spore on the basis of fine-grained structure which would be prominent in the former, but essentially absent in the latter. This concept was supported by the appearance of these two subjects in photographs. The tests conducted using tape recordings from the PACT played back through a high-pass filter designed for this specific purpose led, however, to the conclusion that this approach was not feasible. Subsequently, as a result of the pulse

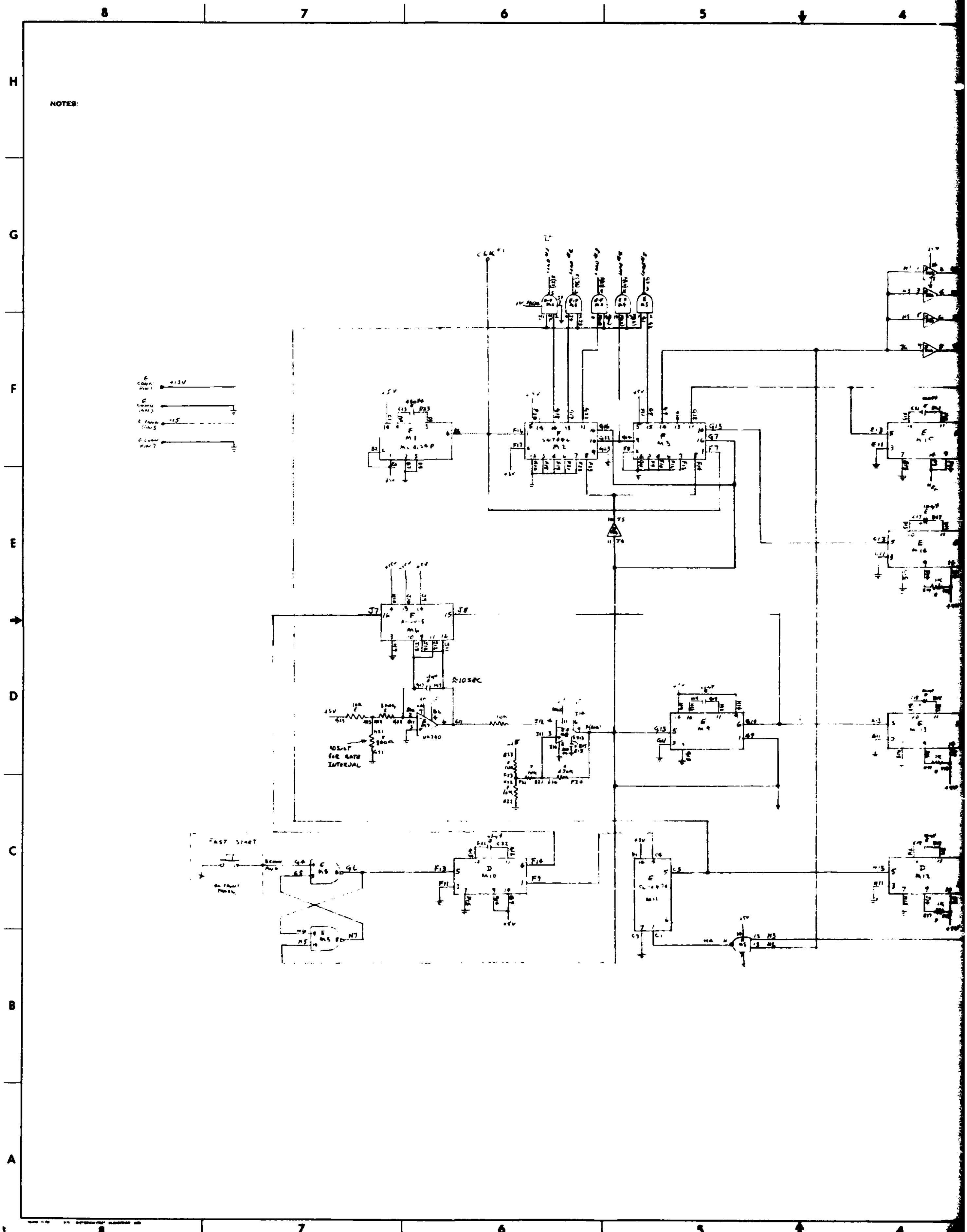
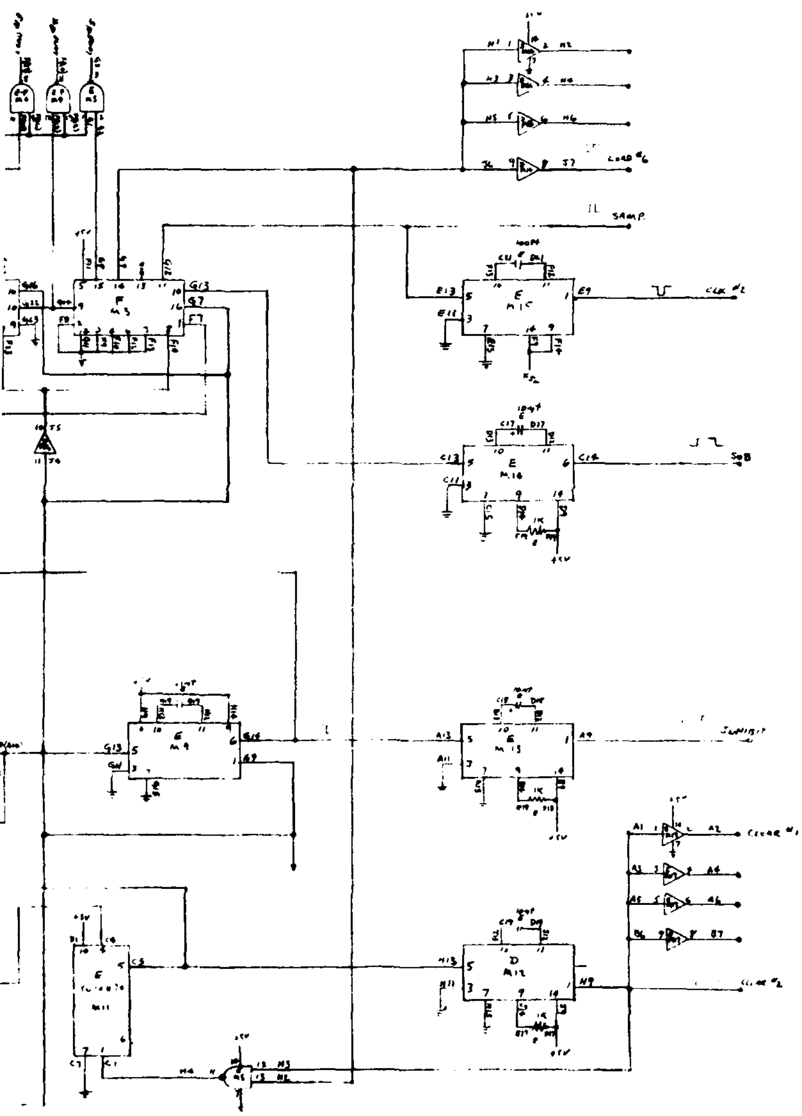


Figure 4-5. Alarm Logic Timing



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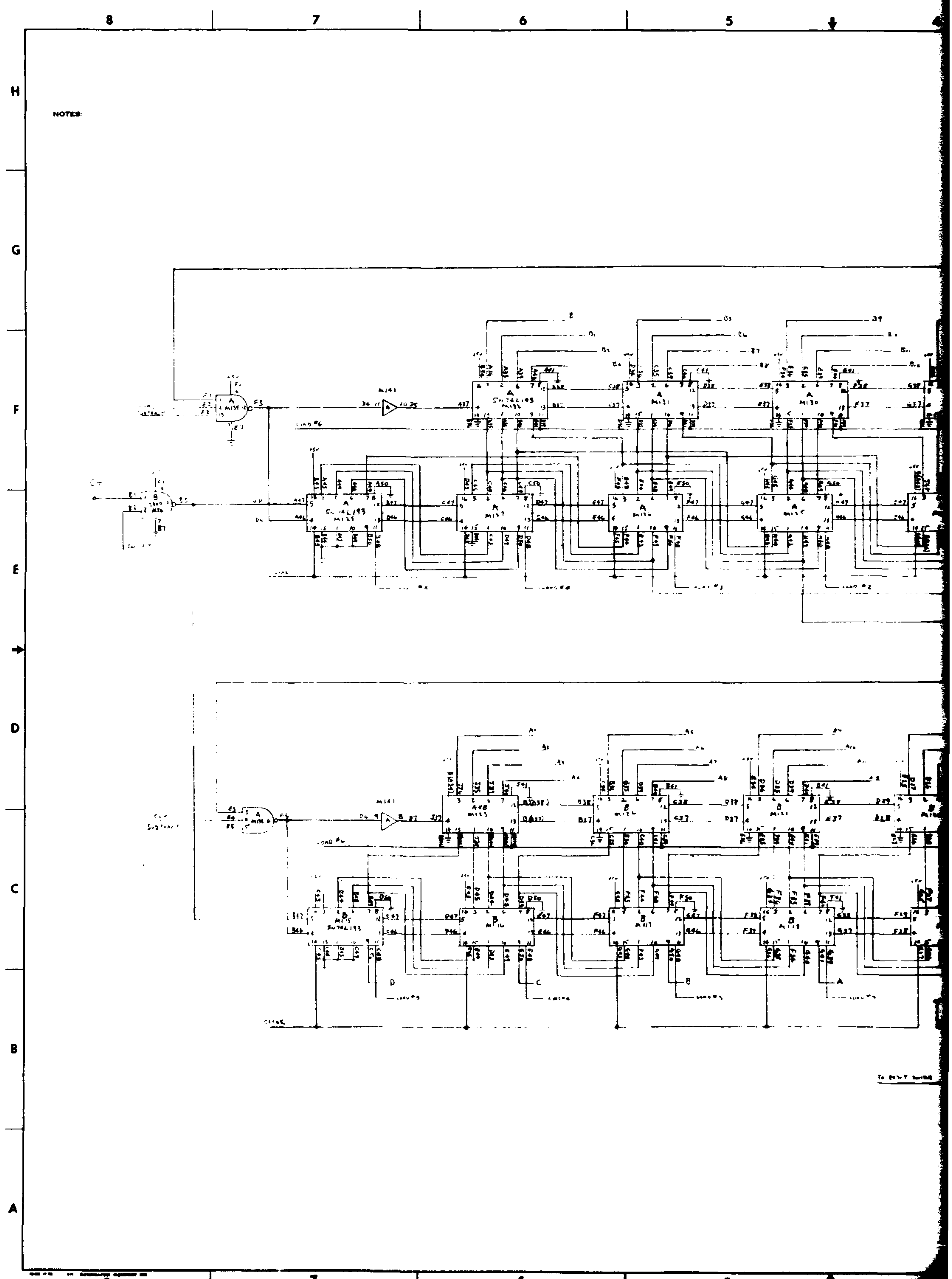

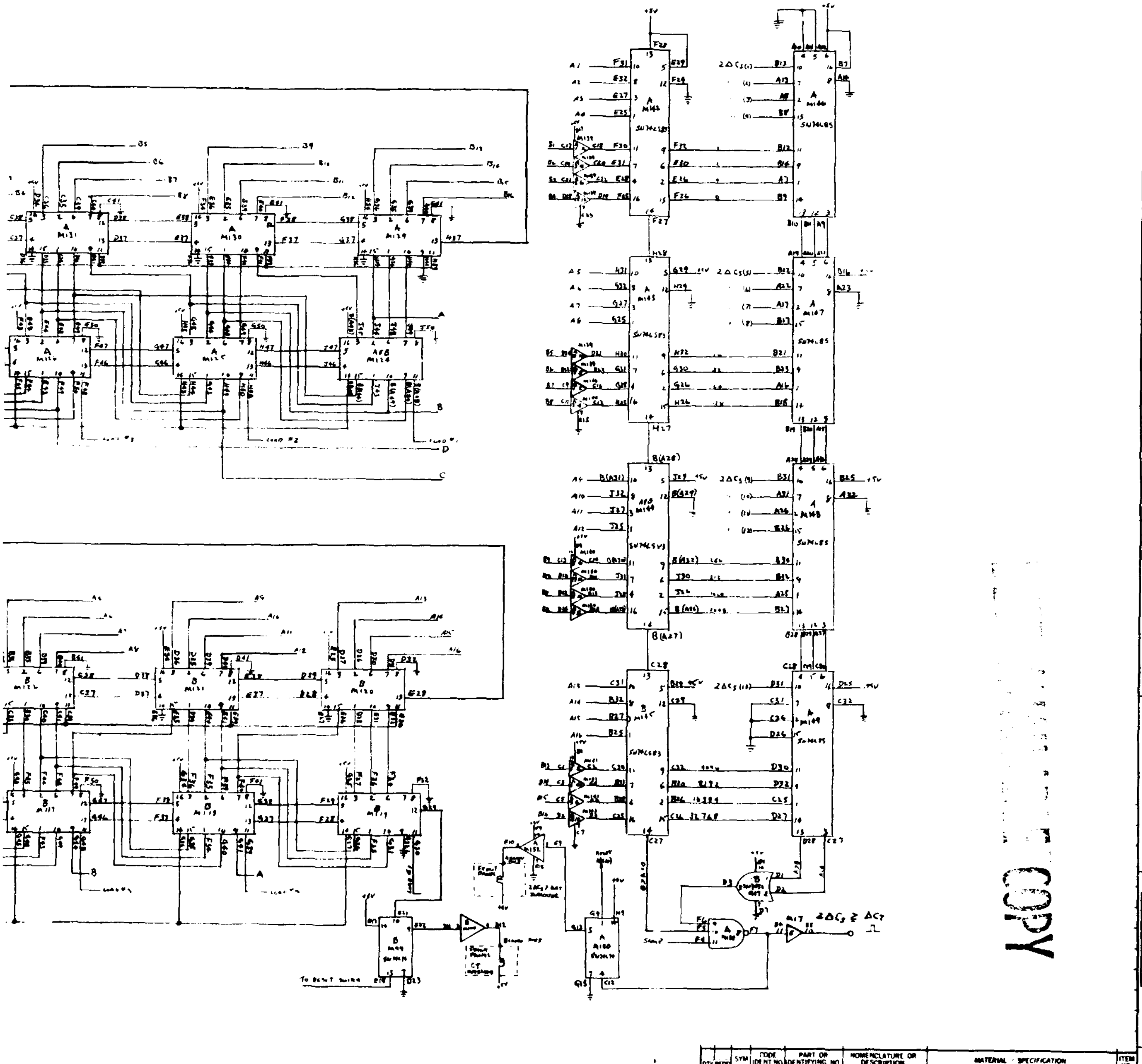

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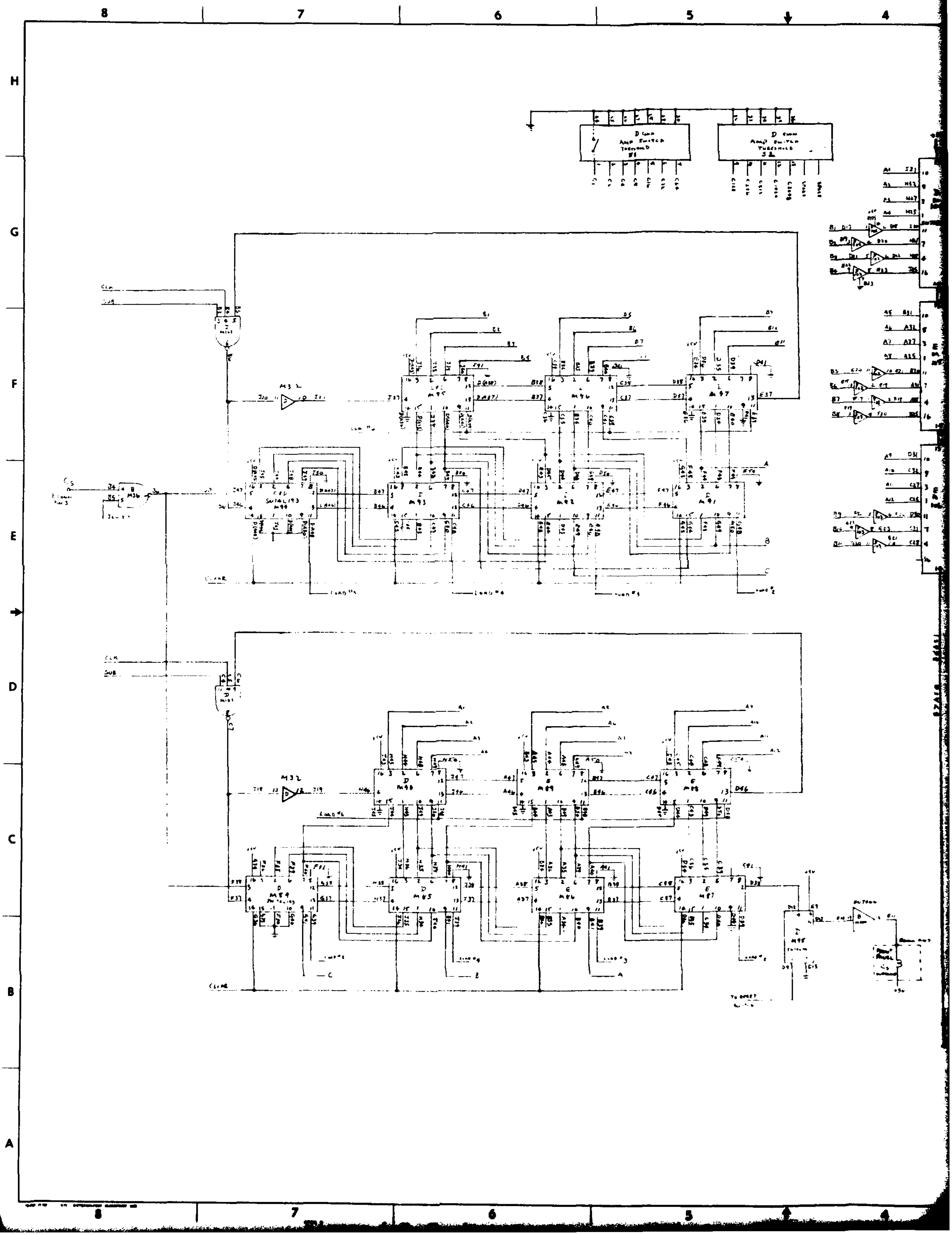
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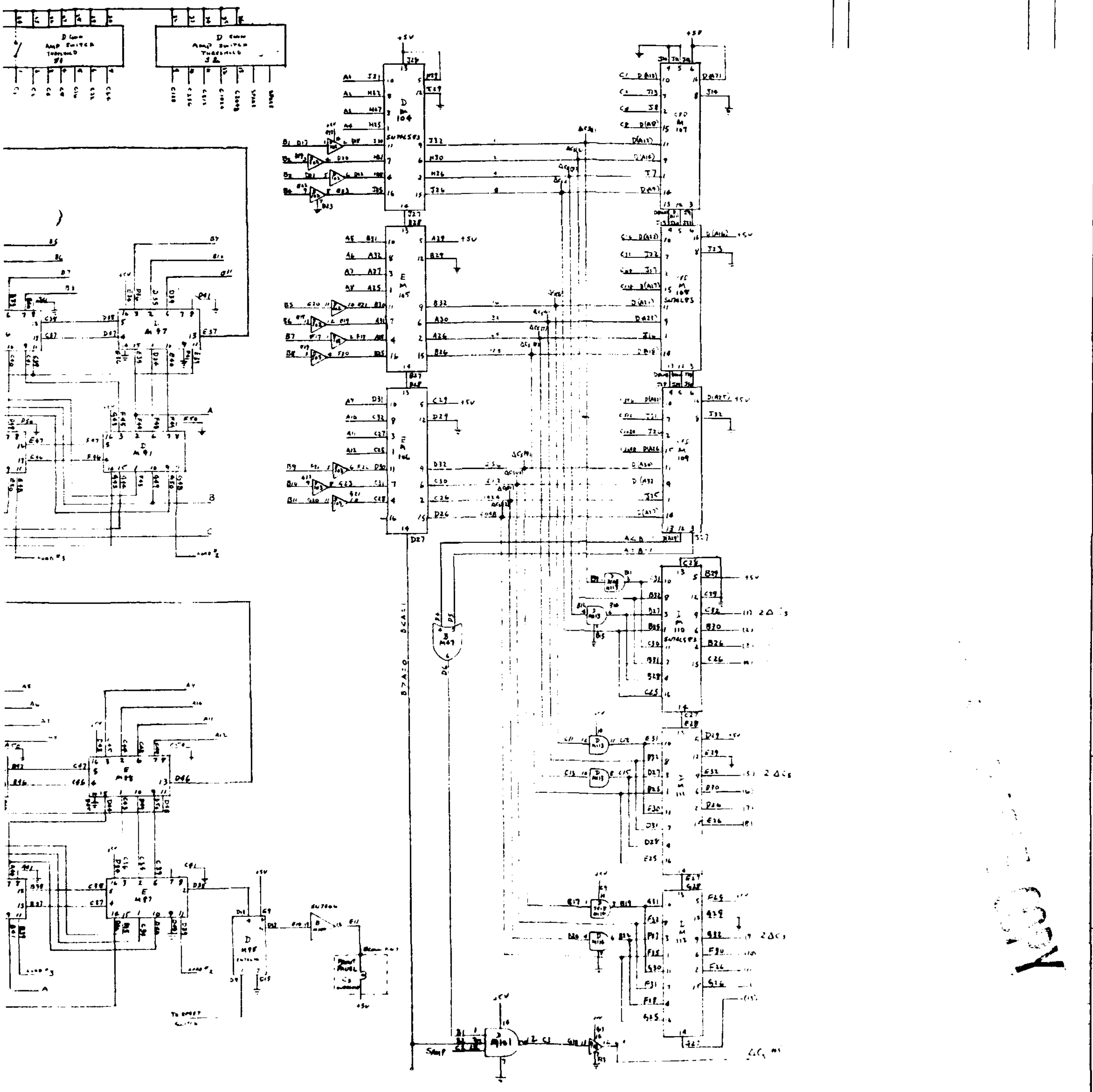

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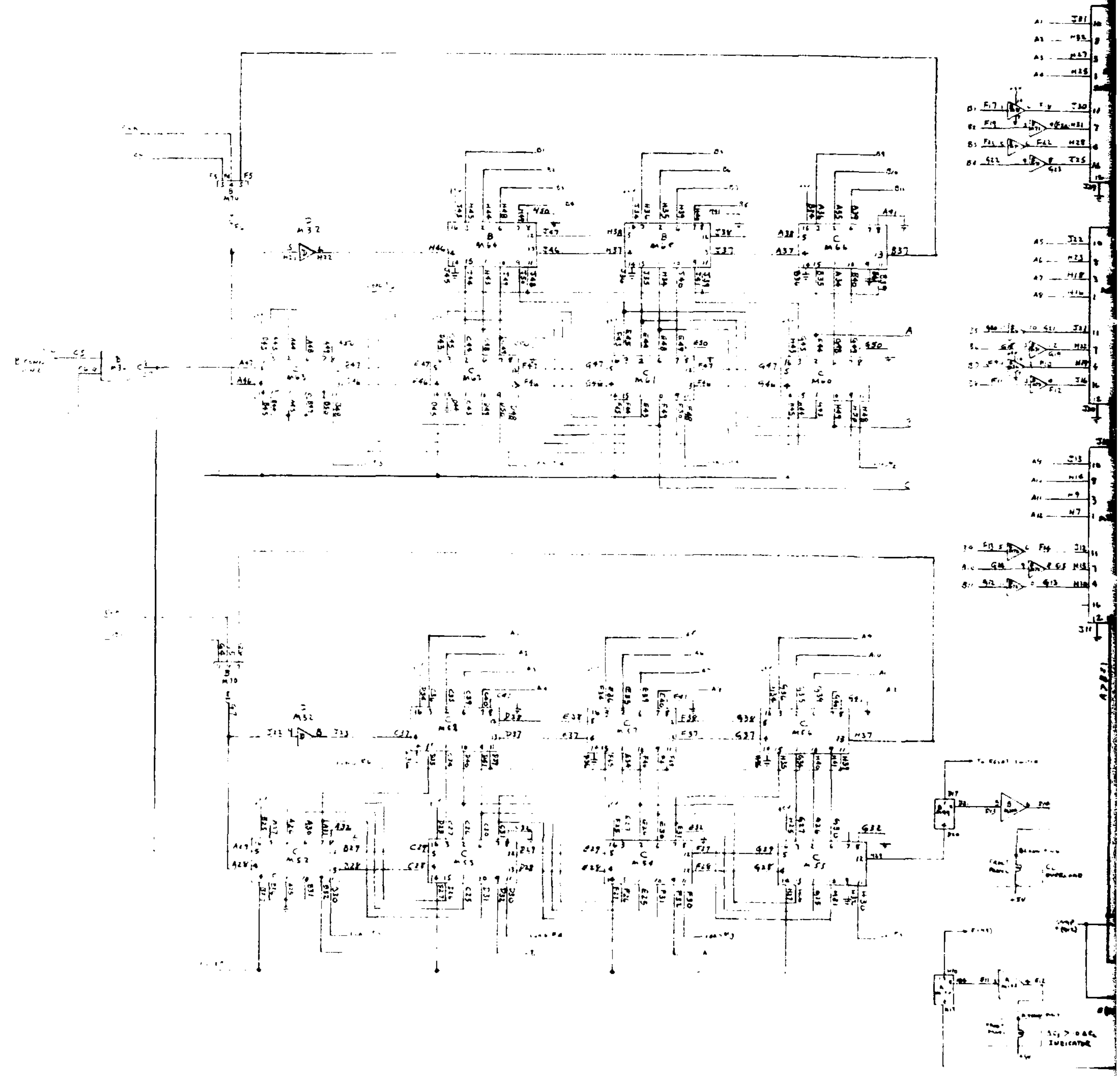

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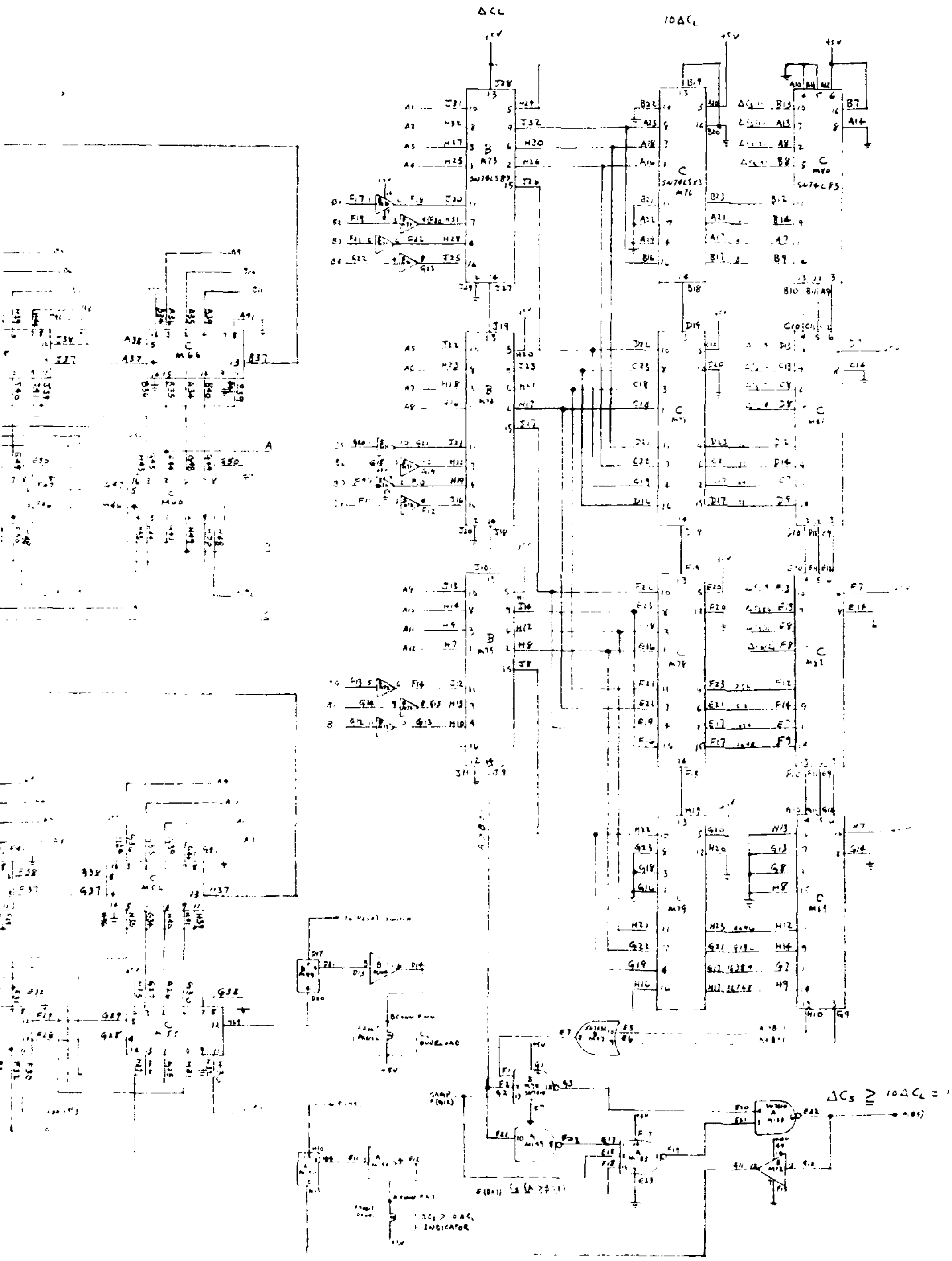

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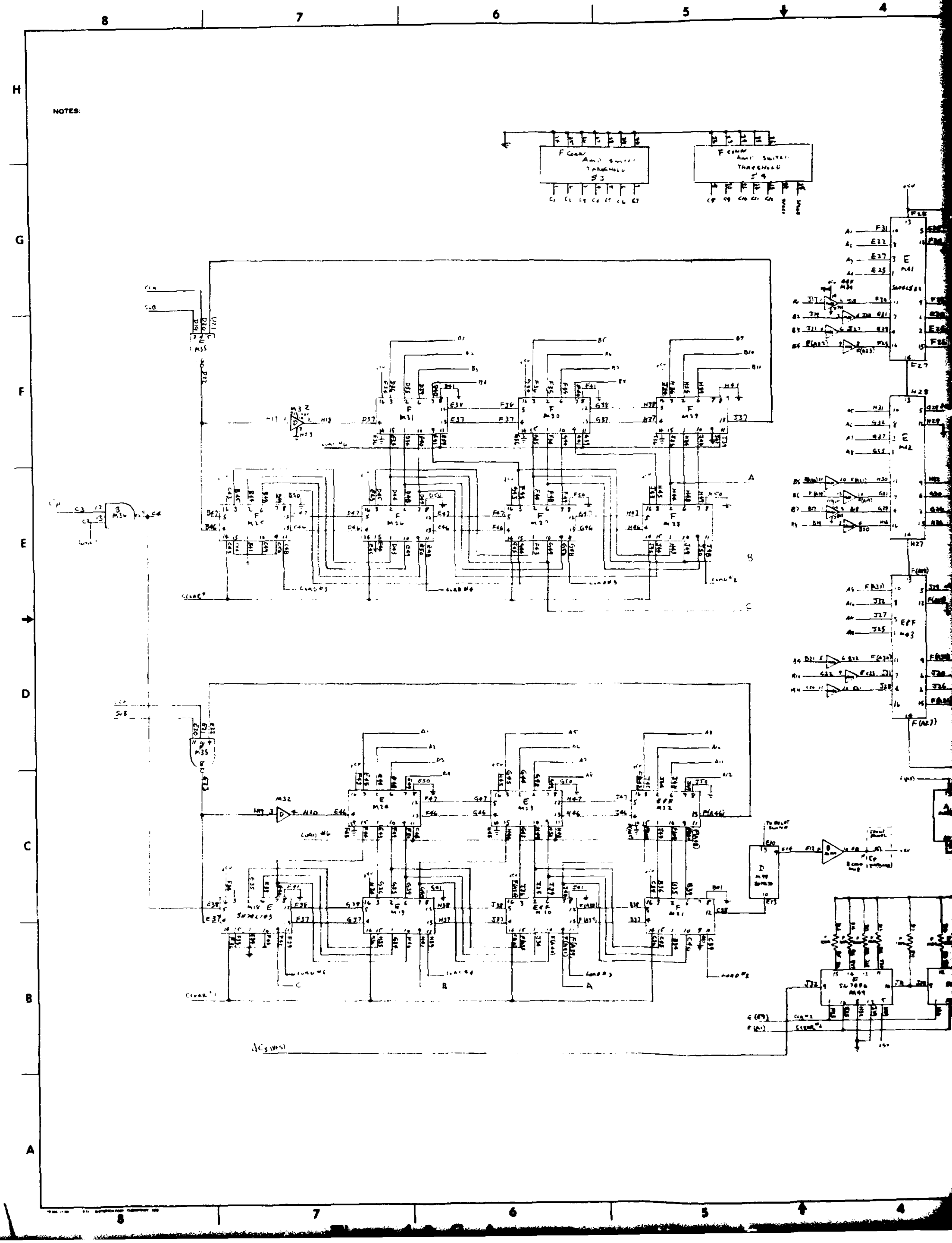

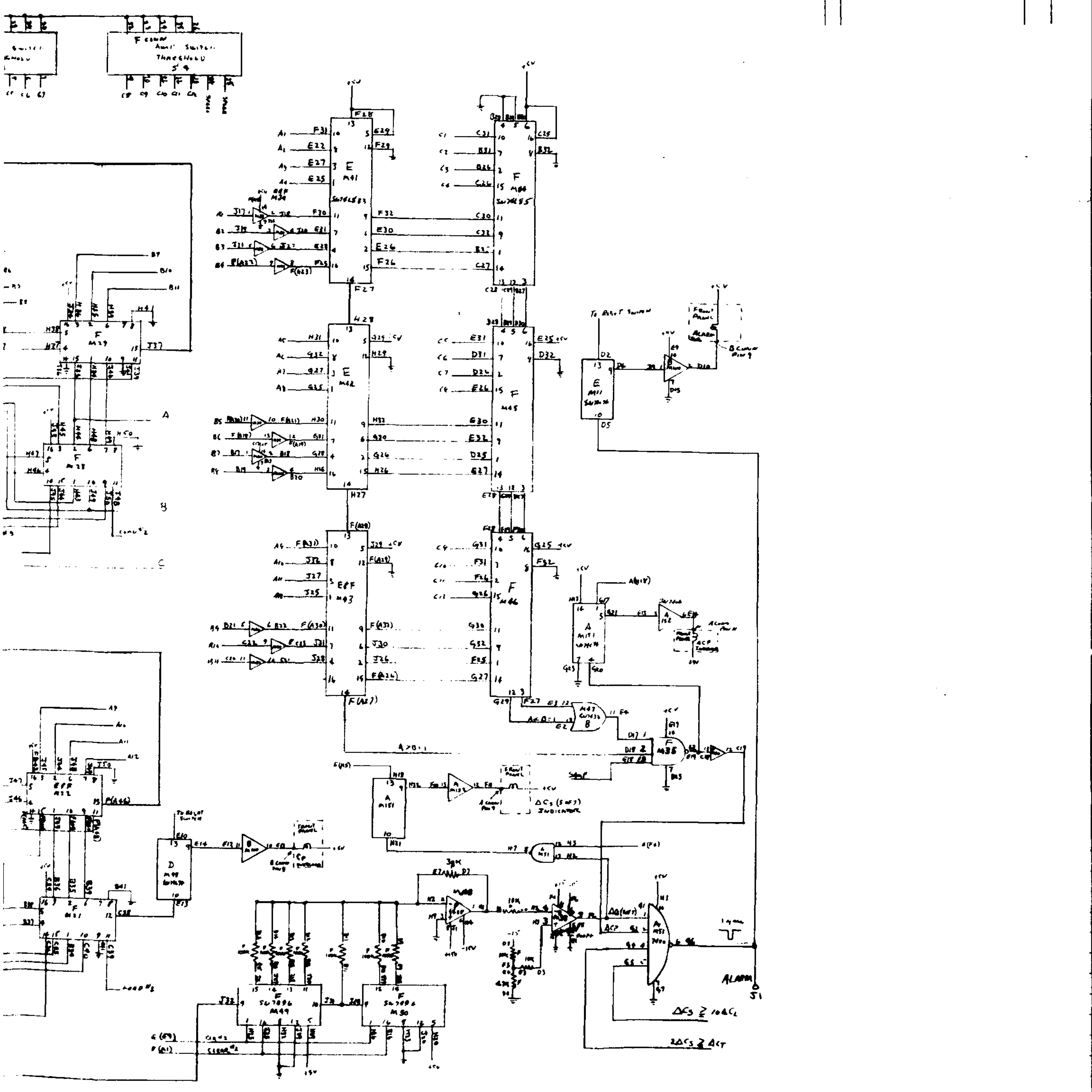

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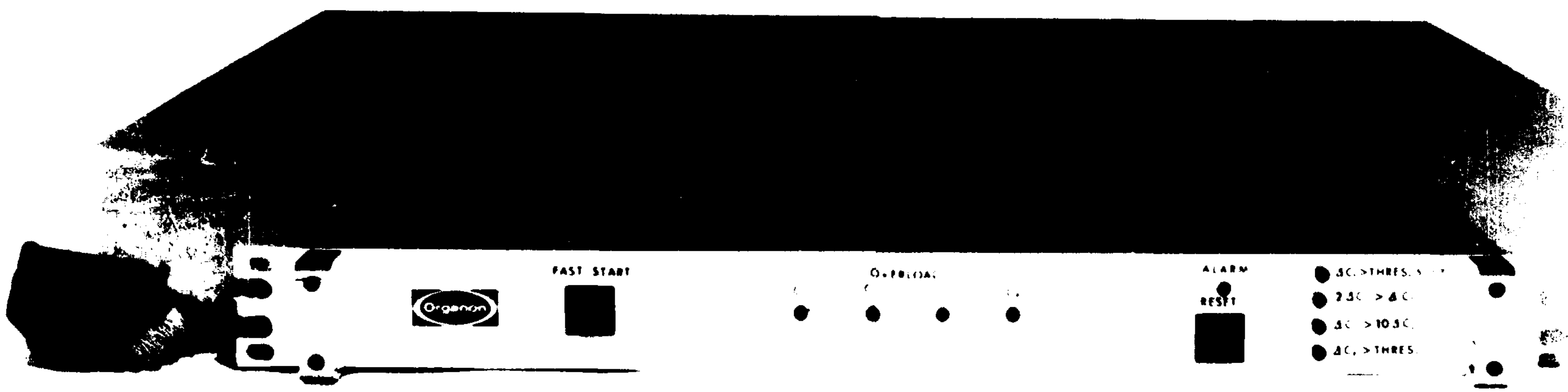


Figure 4-10 Alarm Logic Assembly (Front, Horizontal)

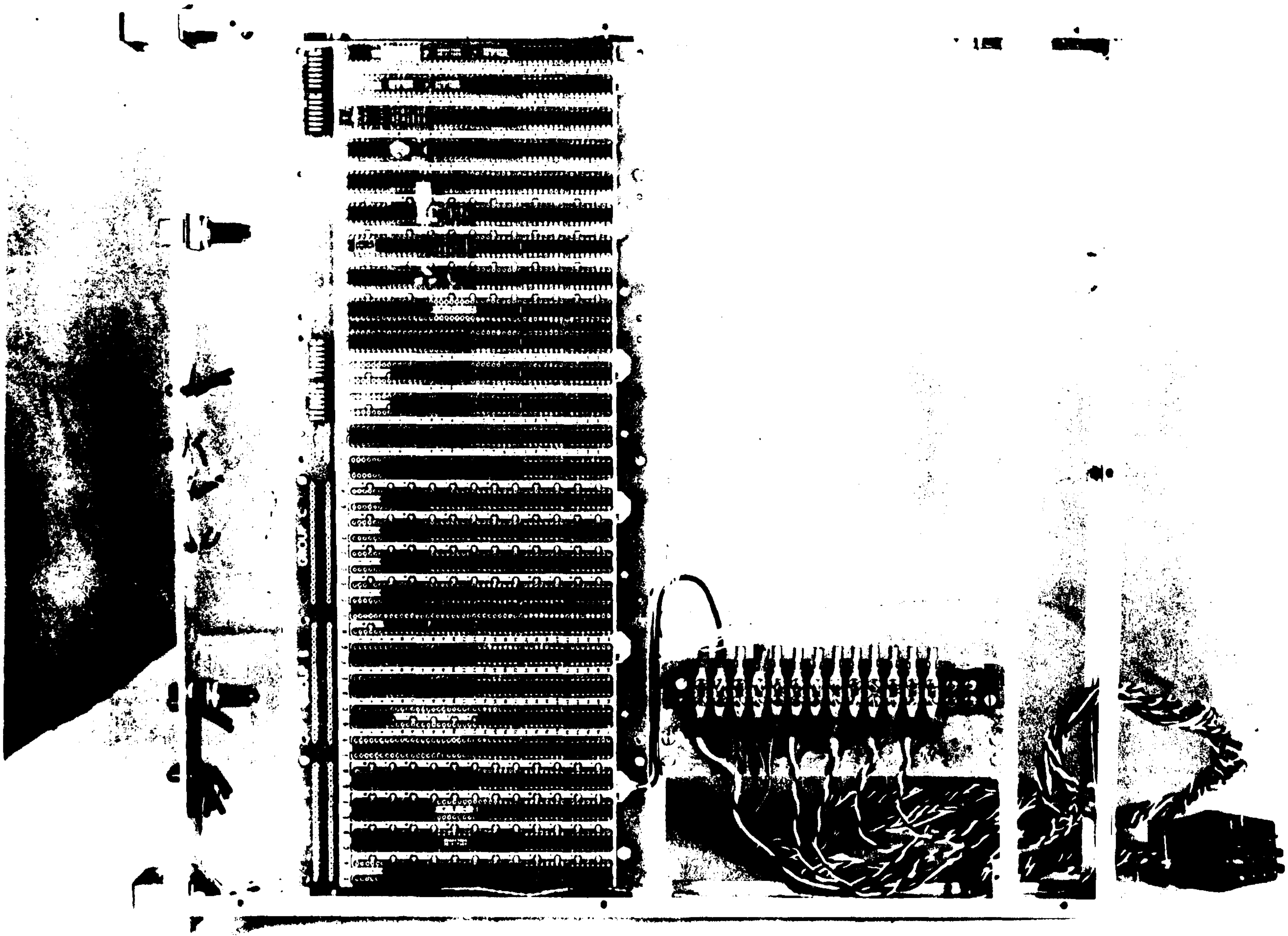


Figure 4-11 Alarm Logic Assembly (Vertical, Top)

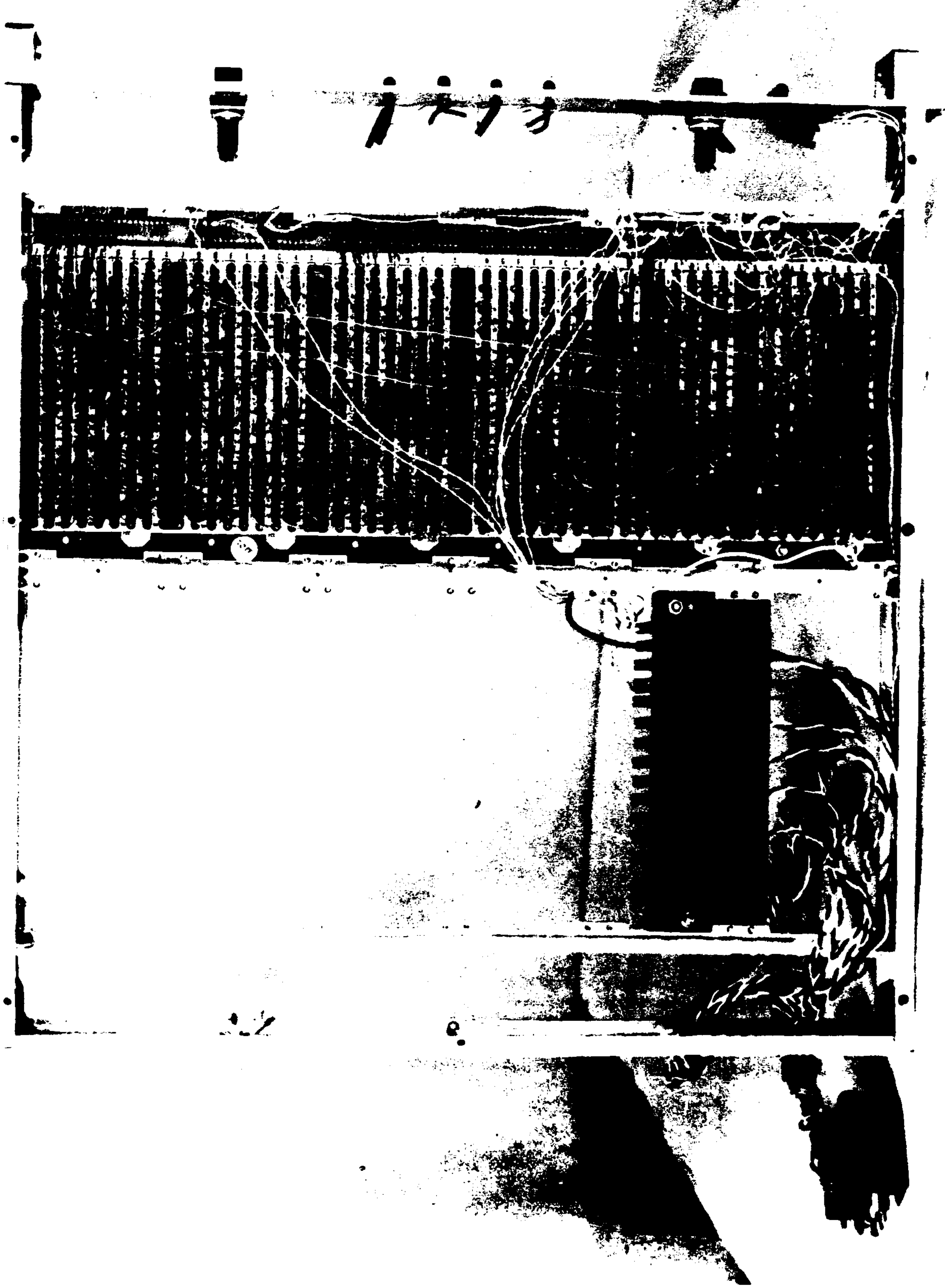


Figure 4-12 Alarm Logic Assembly (Vertical, Bottom)

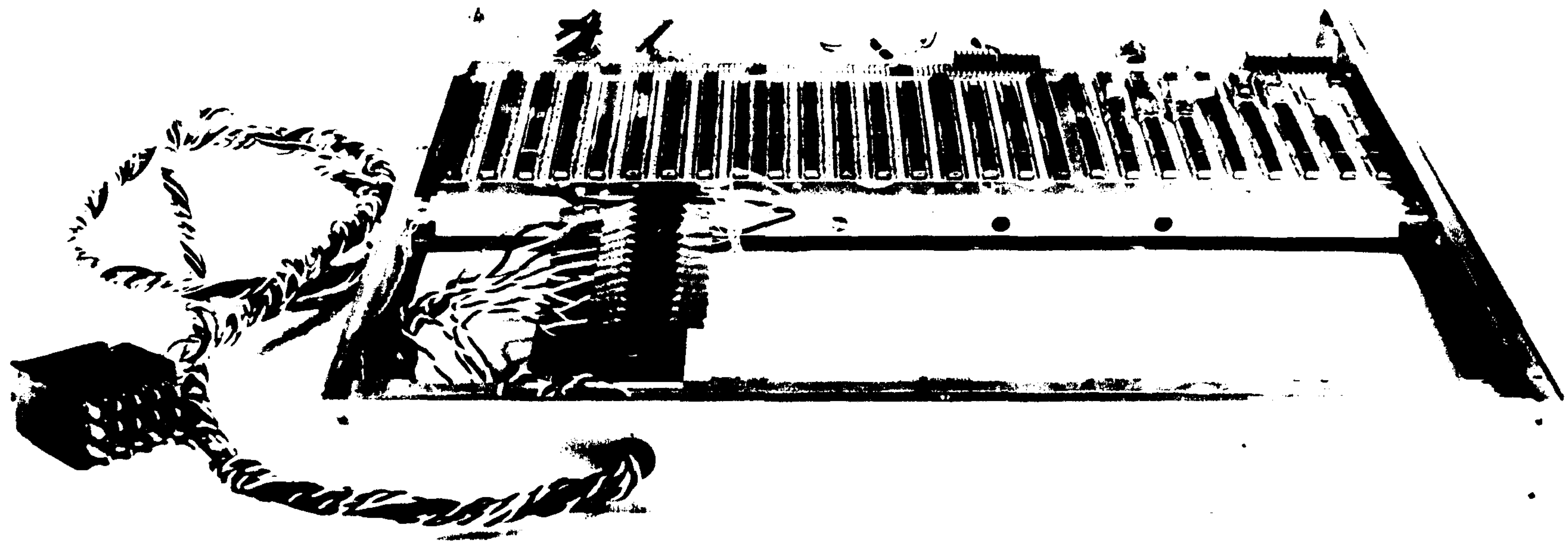


Figure 4-13 Alarm Logic Assembly (Rear, Horizontal)

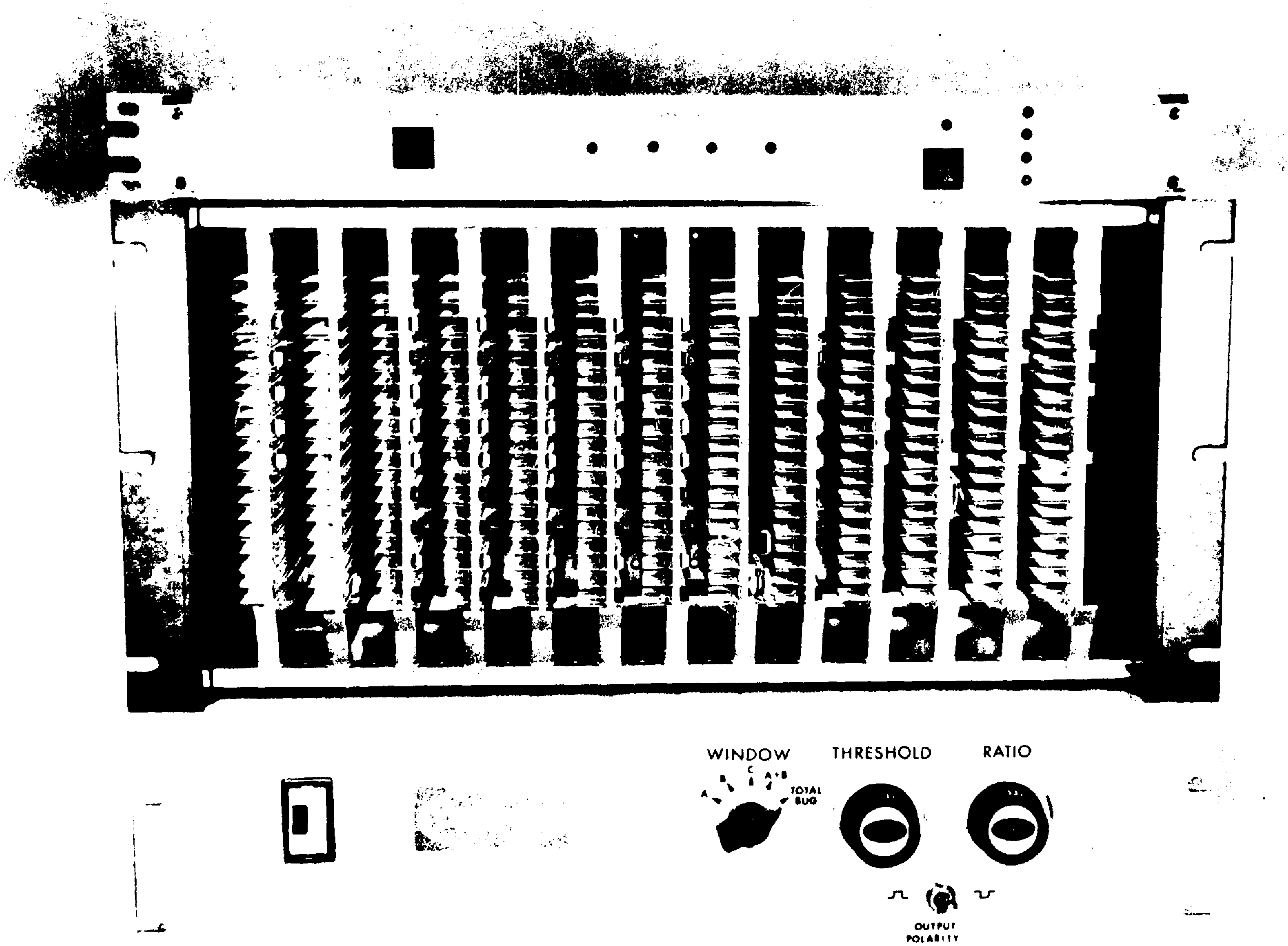
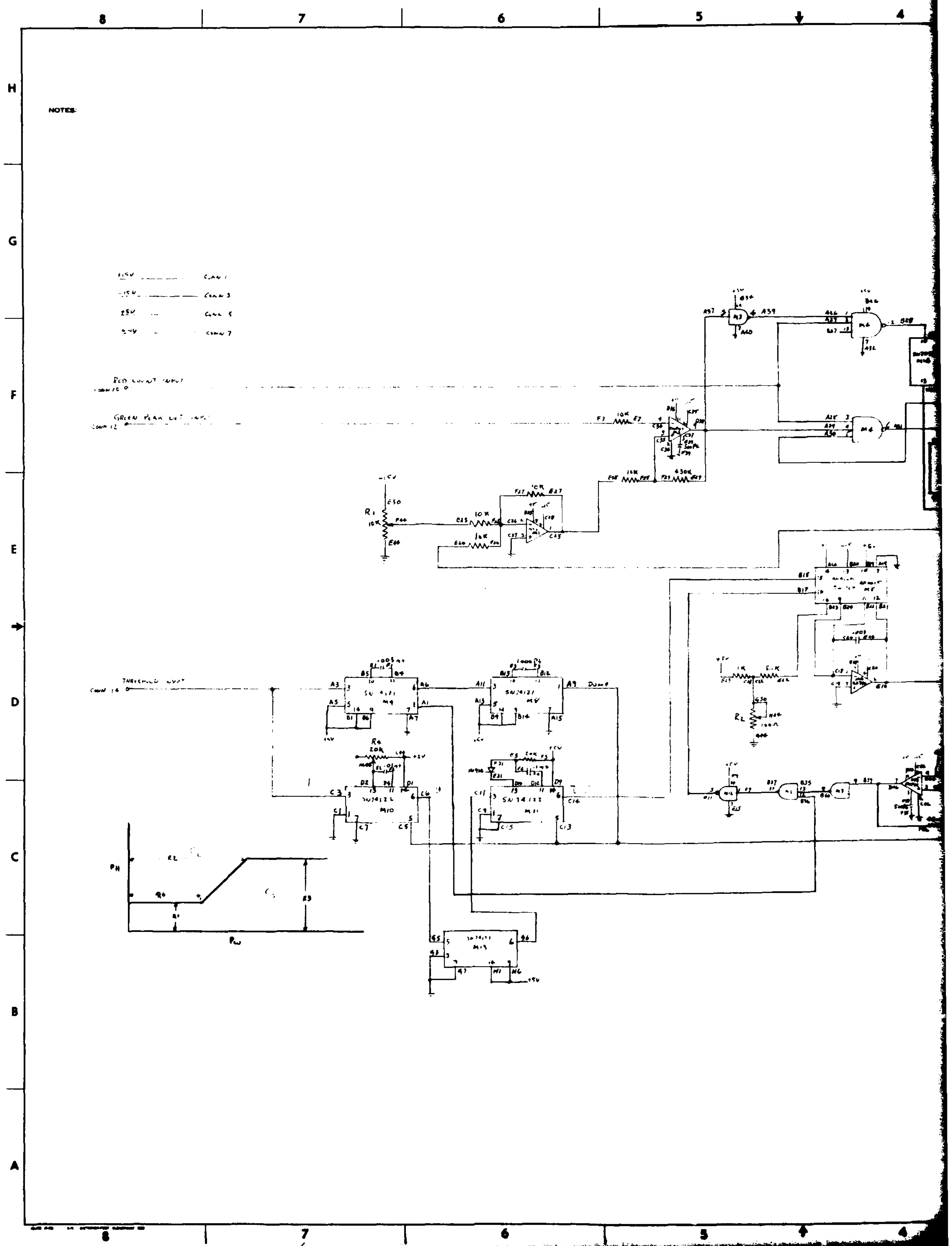


Figure 4-14 Alarm Logic and Card Cage

height/pulse width distribution data obtained on this program, it was found that discrimination between the two was often quite pronounced on the basis of these two parameters. Indeed some degree of separation between the two was already being accomplished on the basis of height alone. Examination of the data showed that an added degree of discrimination could be made by means of a device which separated and classified video pulses as "large" or "small" on the basis of their coordinates on a plot of pulse height and pulse width. The mold spore was seen to occupy an unusual distribution compared to many other agents. Of the agents measured, only the dry select egg (see Figure 3-10) occupies a comparable distribution, and even then the centroid of the distribution is considerably lower.

On the basis of early pulse height-pulse with information, a unit was designed which separates particle counts according to which side of a "zig-zag" line of separation they are situated. The design of this circuit derives many of its concepts from the Pulse-Height/Pulse Width Discriminator which was developed under the previous contract. However, one noteworthy difference is the sloping line partition in the new system. A schematic of the Mold Spore Detector appears in Figure 4-15. This circuit is wired on the Augat card which occupies the remaining slot in the card cage. Potentiometers R_1, R_2, R_3 and R_4 are used in adjusting the position of the partition line separating the large and small particles. R_1 and R_3 adjust the height of the two horizontal portions of the line, while R_2 adjusts the inclination of the sloping portion and R_4 translates horizontally the position of the sloping part of the partition line.



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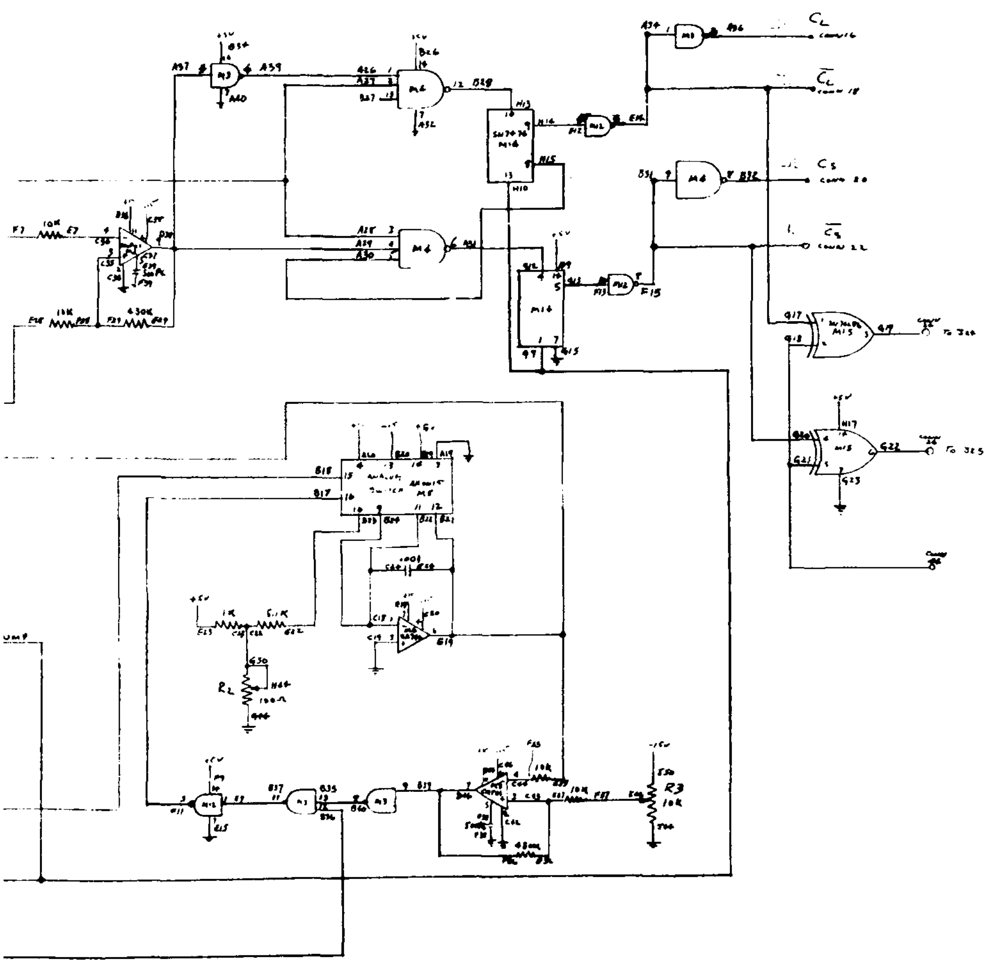

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5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Accomplishments

5.1.1 Task Structure

The task structure specified for the entire program consisted of the following three tasks:

- Optimization of alarm and false alarm sensitivity.
- Development and building of an Alarm Logic System.
- Refining of current pattern recognition electronics to detect egg or reject mold spores.
- Fabricate duplicate pattern recognition circuit boards and Alarm Logic System.

5.1.2 Optimization of Alarm and False Alarm Sensitivity

As stated in Section 3 of this report, the data used for analysis were obtained in the form of FM recordings which were made of PACT signals and conducted early in the program in three separate recording sessions. These tapes were made using the FM-mode, which makes them markedly superior to the earlier direct mode tapes in terms of waveform fidelity. These tapes provided the source of material for analysis of agent and background parameters which facilitated the design development of the pattern recognition electronics. These recordings and their subsequent analysis provided the following:

- A source of background recordings and mathematical models for the two locations (Dugway and Edgewood).
- A library of agent recordings and mathematical models.
- Recordings and analytical data to assist toward evaluation and optimization of existing pattern recognition electronic circuit parameters.

A major output of this first of the three program tasks was the modification of the existing Correlator in view of information obtained from this analysis as well as information obtained earlier. As a result, the correlator "window" has been changed from 4 by 10 elements to 4 by 5 elements, eliminating unnecessary storage; the AGC has been deleted since it was found to be degrading the performance of the correlator slightly; and dual pairs of correlator profiles incorporated to enhance further the performance. These considerations are discussed further in Sections 4.1 and 5.2 of this report.

5.1.3 Development and Building of an Alarm Logic System

A major portion of the hardware development effort on this program was the generation of an entirely new subsystem to be integrated with the existing pattern recognition electronics. This new component is the Alarm Logic System which takes four signal inputs from the pattern recognition electronics and processes them and subjects the data to certain sets of requirements of logic and provides an alarm indication if these requirements are satisfied. Two duplicate units were required by the customer, to be integrated with the two existing systems. The units are wired each on a single large Augat board and mounted in a separate rack panel mount.

5.1.4 Refining of Current Pattern Recognition Electronics

In addition to the modification of the pattern recognition electronics mentioned in Section 5.1.2, an additional requirement was the inclusion of new hardware into the current system to enhance its ability to reject mold spores, especially in view of the similarity which these common organisms have to egg challenges. Such a modification resulted in the addition of another new component to the existing pattern recognition system. This new component is termed the Mold Spore Detector and its function is to separate the counts resulting from video pulses into two categories, on the basis of amplitude and width characteristics of the video pulses, according to a specific sorting criterion which is described in Section 4.3 of this report. Two duplicate units of this Mold Spore Detector were fabricated, one of them to be integrated with each of the two existing pattern recognition systems.

5.1.5 Fabricate Duplicate Electronic Circuits

During the extension portion of the program, a complete set of spare circuit boards, i.e. -one board of each type was fabricated to serve as backups in case of future board malfunction in a field test situation. The severe boards thus fabricated specifically are as follows:

Improved resolution detector

Pulse height/pulse width discriminator

Timing generator

Summing circuit

X and Y correlator

Y multiplexer

Mold spore detector

In addition, a complete hardwired Alarm Logic System also was fabricated for the same purpose. All of these duplicate components subsequently were checked out.

This task was continued during the extension of the program with a concentration of attention on upgrading the Mold Spore Detector (see 5.1.4 above) by obtaining more detailed analysis of pulse height/pulse width data and subsequent evaluation of the problem.

5.2 Conclusions

5.2.1 Data Acquisition

The three data acquisition sessions conducted at Dugway and Edgewood have provided a well-equipped library of PACT video recordings which include a fairly comprehensive selection of agents which can be used at any time that tests using a particular agent may be desired. In addition, background recordings for both Dugway and Edgewood were obtained, as well as a recording of mold spores and one of yeast which may prove useful for test purposes. Since the recordings were made in the FM-mode for both the red and the green video channels, these recordings are of very high quality. These recordings were made on a Hewlett Packard 3950B instrumentation tape recorder owned by Organon Diagnostics providing a signal bandwidth of 200 kHz, which is more than twice that of the PACT video output.

5.2.2 Data Analysis

The analysis of the data obtained has provided a more complete and more accurate picture of the nature of the signals than had been obtained in the previous program. These advantages result from the following factors:

- The data was obtained from higher quality FM-mode recordings which permitted a more accurate preservation of signal parameters than was possible using the direct-mode recordings of the previous program.

- The data was reduced directly, using the pattern recognition electronics which were adapted for this purpose (some of the data reduction also made use of some simple breadboard circuitry). This direct reduction of data permitted a much larger statistical sample to be used.

- Experience obtained through the process of reducing and analyzing data on the earlier program including observations made in this regard permitted the generating of more complete and useful data as well as a more useful format of data presentation.

As a result of these considerations, the resulting data analysis provides a very useful source of information, not only for the immediate requirements of this program, but for a wide variety of future requirements in adjusting or adapting PACT or related equipment.

The data results are in two categories:

- Pulse parameter distributions, i.e., pulse-height and pulse-width (See Section 3.2).

- Clump density distribution (See Section 3.3).

New data on green/red ratio distributions were not necessary, since the old data from the previous program provides a good representation of this information. The reason for this is that this parameter should reflect little or no discernible effect from the use of the earlier direct-mode video recordings and also the format of presentation of the reduced data was highly satisfactory.

5.2.3 Modifications to Existing Correlator

One major application of the above data analysis was its use in the modification of the correlator in the existing pattern recognition system. The primary goal of this modification was the enhancement of its performance in separating agent signals from the background. The data which was applicable toward this particular subtask was the second group of data mentioned above, specifically the clump distributions for various agents.

Initial effort was directed toward optimizing the 4 by 5 correlator design by means of a computer program using a Hewlett-Packard 9100B programmable calculator. This program effectively varied the values of the two sets of resistors to optimize the ratio of correlator output amplitudes between an "average" agent and an "average" background. The "average" agent used has x and y profile characteristics which were an average of those of eight agents of interest, while the "average" background was an average of samples of Dugway and Edgewood backgrounds. Using this procedure, an optimum profile for the 5 x-axis resistors was obtained; similarly, an optimum profile for the 4 y-axis resistors was computed. In addition, it was noted from examination of the clump distribution data that the difference between agents and background often tended to be quite marked on the width of the skirts of the profiles. Thus a further enhancement of the distinguishability between agent and background could be made using correlator profiles which de-emphasized the center of the "window" and emphasized the edges. Other modifications of the correlator facilitated a dual function configuration using two different profiles on both axes with separate detectors whose outputs are fed to AND-gates (see Figure 4-3).

5.2.4 Alarm Logic System

A new component developed and fabricated under this program is the Alarm Logic System. This subsystem is wired on a large, 5-section Augat board mounted in an individual rack panel. Its design, while utilizing basic digital principles, is fairly complex and is discussed in some detail in Section 4.2.

The Alarm Logic System provides an effective interface between the operator and the PACT/pattern recognition combination. It processes four separate outputs from the latter according to a group of logic decisions and presents to the operator a go/no go indication regarding the presence of an alarm condition. This subsystem has given excellent performance in laboratory tests using tape recorded PACT signals.

5.2.5 Mold Spore Detector

The Mold Spore Detector is the other new subsystem developed and fabricated on this contract. Its purpose is to facilitate the refinement of the pattern recognition system in order to enhance its ability to separate mold spore signals from among legitimate challenges, especially egg signals which often closely resemble mold spores, as seen by the electronics. This new subsystem separates stained material into two categories according to their video pulse height and pulse width characteristics, as described in detail in Section 4.3 of this report. This unit provides a significant improvement over the earlier method of separating the particles on the basis of pulse height alone. The Mold Spore Detector is wired on an Augat card which occupies the one remaining location in the card cage.

The problem of enhancing the ability of the Mold Spore Detector to distinguish mold spores from valid agents was given special attention in the analysis phase of the program extension. During this continuation of the program, detailed empirical data was taken to a large degree for this purpose. Of special interest among agents is the dry select egg whose pulse height/pulse width resembles closely that of mold spore. Also of some degree of interest is the wet select egg because of its frequent wide, low-amplitude pulses.

The new data taken during the program extension has resulted in some very significant deductions. First the data tends to confirm that the present basis of sorting out the mold spores by pulse height/pulse width criteria is a very valid approach which can be refined so as to enhance its effectiveness very significantly. Second, the data plots indicate that the present mold spore detector technique of dividing out the mold spore by means of the horizontal zig-zag line will not be able to make the most effective use of this method. Rather (and third) it has indicated that a much higher degree of separation can be achieved by using a three-window approach in conjunction with some ratio and thresholding circuits.

To illustrate this mode of operation, Figure 5-1, 5-2 and 5-3 show a set of three pulse height/pulse width windows labeled "A", "B" and "C" superimposed on the contours of three different agents. Based upon the count percentages indicated on the charts (the chart information is discussed in Section 3 of this report), we may tabulate the data as follows:

TABLE 5-1 PERCENT OF AGENT INTERCEPTED BY EACH WINDOW

Agent	Window A	Window B	Window C
Wet mold spore	4%	62% +	14%
Dry select egg	16%	56% +	2%
Wet select egg	$2\frac{1}{2}$% +	$7\frac{1}{2}$% +	49%

Above, the plus signs indicate that there would probably be more counts beyond the boundary of the data taken. It should be noted that Window B extends off the chart. This choice in boundaries was

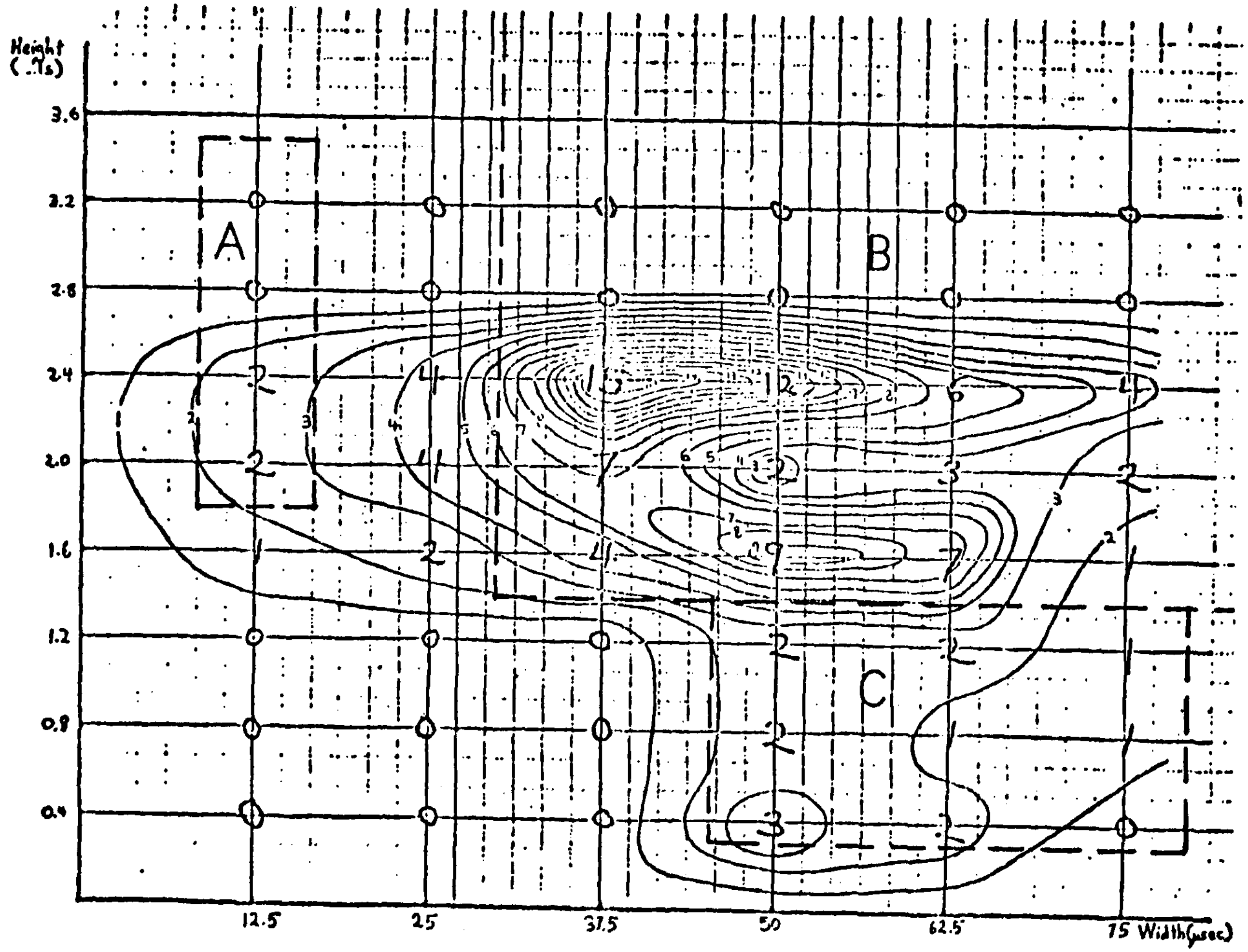

Figure 5-1 Wet Mold Rate-of-Occurrence Contour Plot Showing Windows

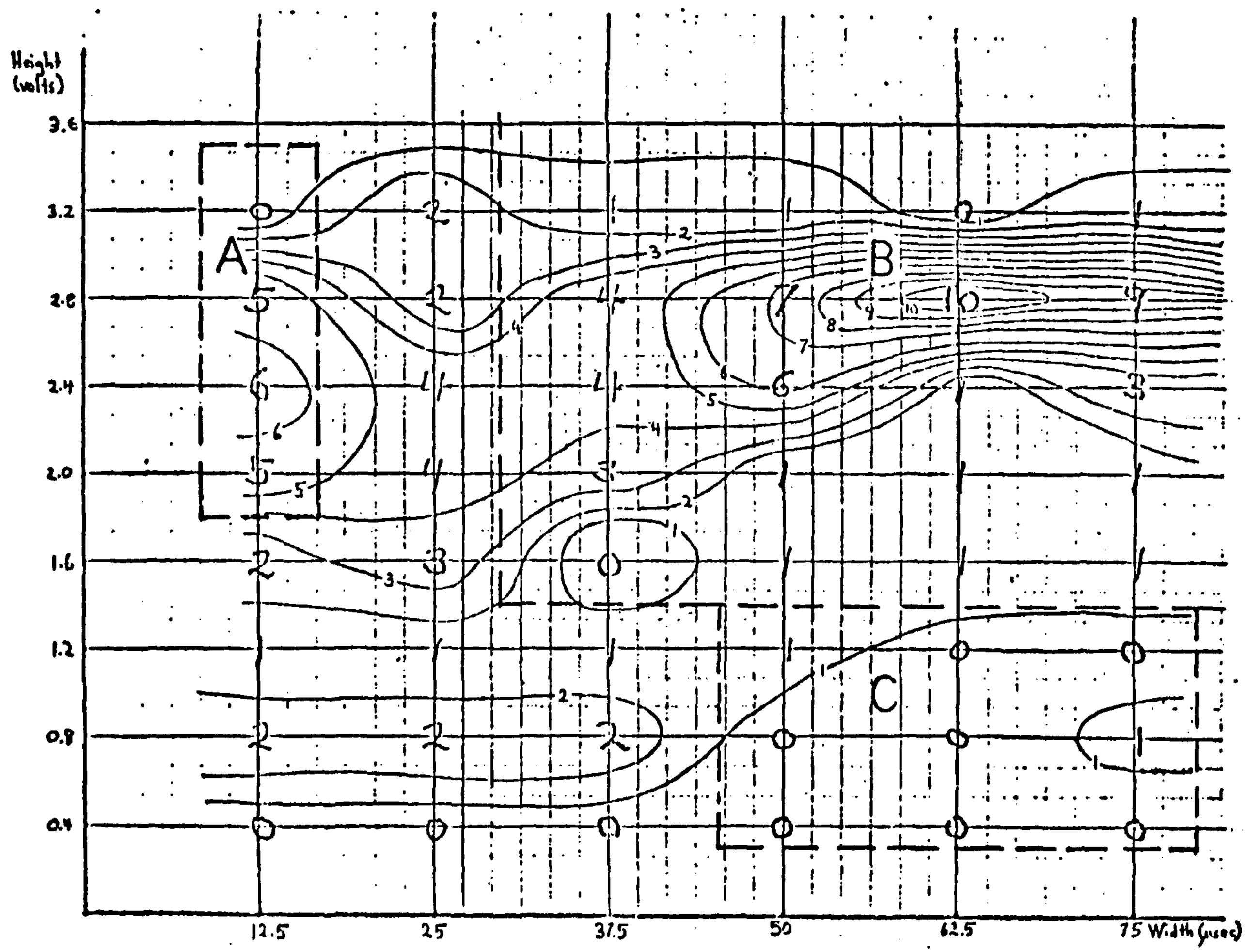

Figure 5-2 Dry Select Egg Rate-of-Occurrence Contour Plot Showing Windows

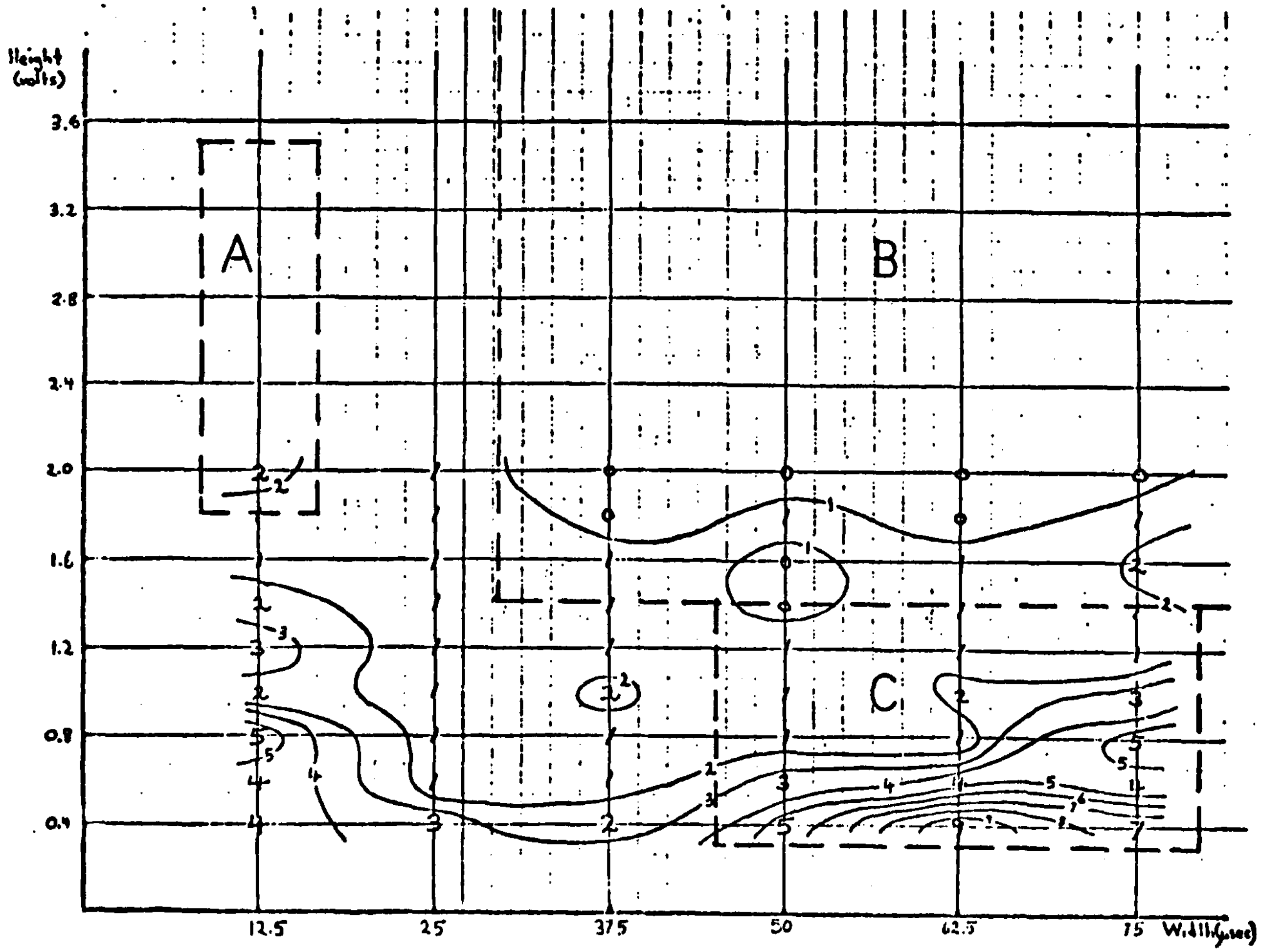

Figure 5-3 Wet Select Egg Rate-of-Occurrence Contour Plot Showing Windows

made to accommodate varying sizes of mold spores. It is immediately evident from Table 5-1 that the distribution of counts among the windows varies drastically from agent to agent. The wet mold spore may be easily distinguished from dry select egg (difficult by previous means) by observing the count ratio A/C. For wet mold spore it is only 0.29, whereas in the case of the dry select egg, it rises to 8.0! Thus, we see about a 25-fold change in this parameter between agents. Like the mold spore, the wet select egg has a low value for A/C; however, it may be easily distinguished by its much lower count rate through Window B.

Based upon the above considerations, a new three-window mold spore detector which senses the window ratios A/C and B/C through adjustable thresholds is recommended. With the current mold spore detector, a straight-across division between large and small counts set at about 1.4 volts appears to be about optimum although it will also screen out most of the dry select egg.

5.2.6 Overall System Performance

Figure 5-4 is a plot of data obtained using the integrated pattern recognition system. The signal source used was the tape recording made at Dugway of a Sm cloud which was released in open air and arriving about 2 1/2 minutes after the beginning of the data shown. Thus, the first couple of minutes represent more-or-less pure Dugway background with the Sm cloud coming in after that and building up to a maximum at about 8 or 9 minutes and then dying out, with the air samples returning toward Dugway background. During this run, which was made using the Dugway tape, the functions of the Alarm Logic System, operating in conjunction with the rest of the pattern recognition electronics, was monitored and these functions are shown in Figure 5-4 where the lower curve shows the total red counts per 10-second gate. The following four conditions must be fulfilled in the Alarm Logic System to produce an alarm:

- ΔC_s greater than threshold for 5 out of 7 times.
- $2 \Delta C_s$ greater than ΔC_t.
- ΔC_s greater than $10 \Delta C_L$.
- ΔC_p greater than threshold.

Each of these functions is displayed on the front panel of the Alarm Logic System by means of four green lamps on the right side of the panel. A fifth lamp, which is red, indicates an alarm condition which is satisfied when the first four lamps are illuminated. All of these functions are shown in Figure 5-4. It is seen that some of the four conditions are occasionally satisfied, but not until about 220 seconds are all four satisfied simultaneously at which time the red alarm lamp comes on. An alarm condition continues until after the 660 second point. As the Sm cloud dies out, the lamps begin to drop out one by one with one coming back on briefly before finally going out (see Figure 5-4). Although the alarm condition has ceased, the red light will remain on until reset by the operator. This feature thus allows for human factors in allowing the operator to be alerted before the alarm lamp is extinguished manually. However, Figure 5-4 only shows the actual period when the alarm conditions are satisfied in the logic.

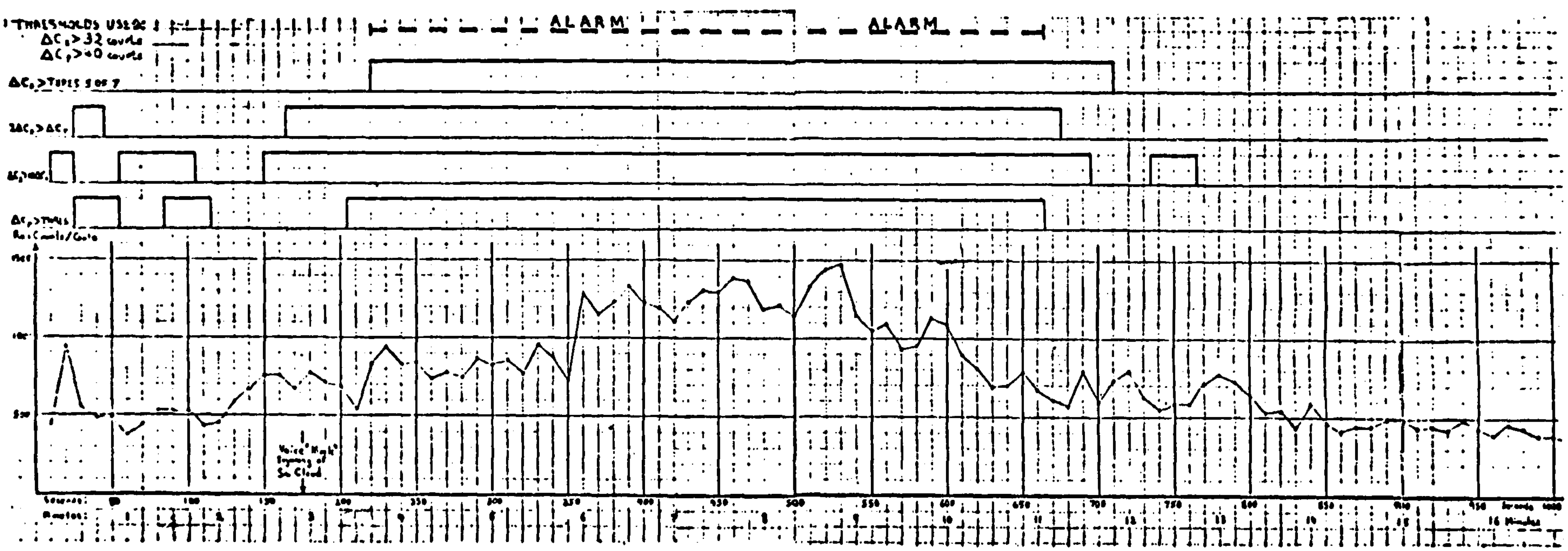

Figure 5-4 System Operation During Release of Sm Cloud

In addition, a series of runs were made using various tape recorded subjects. The resultant test data (see Table 5-II) serves to demonstrate the performance of the overall pattern recognition system utilizing the new subsystems as well as modifications which were introduced in this program. The data show the results obtained with a combination of threshold settings whose values were obtained experimentally by making various runs of the data through the system and making adjustments to obtain more nearly optimum results. It should be noted that the great majority of agents of interest and simulants in this list yielded sensitivities of from about two to six times that of the three pure background samples which were run. Only the VEE, wet select egg, and the two Pt samples exhibited low sensitivities. It should be noted that two of these four runs were made at Dugway where some difficulties were experienced with the PACT. system with regard to electronic noise and with regard to optical focusing. It is possible that one or both of these two recordings were degraded in either or both of these ways; however, the fact that the other two recordings yielded comparable sensitivities suggests that further system analysis, testing and adjustments are to be recommended in order to refine overall system performance to an even higher level. Nevertheless, it should be pointed out that while these relative sensitivites are low, they are computed on a particle-for-particle basis. Thus, even with present adjustment settings, these more difficult agents will be seen readily when their particle counts are a few times higher than the red particle count of the ambient background.

It should be noted that the high detection rate obtained for wet mold spore may not be at all representative since this was from a run which was artificially deployed in an aerosol like a challenge with a resultant tendency to form clumps. This effect appeared very pronounced on an oscilloscope. Natural mold spore occurrences should be uniparticulate and thus may not "fool" the pattern recognition system. This position is reinforced further by the very low sensitivity which the system showed to wet yeast. The yeast, while containing large particles, yielded a sensitivity almost an order of magnitude lower than the mold spore.

The data in Figure 5-4 and Table 5-2 help to illustrate some of the capabilities of the pattern recognition electronics in combination with the PACT system as an effective, automatic bioalarm system which is capable of clearly distinguishing a wide variety of challenges and simulants in the midst of background and producing an alarm to alert the operator. This system warrants recognition as an effective bioalarm and consideration for future refinement in terms of packaging for convenient field use, etc.

5.3 Recommendations for Future System Development

The completion of this program represents an important milestone in the development of pattern recognition as applied to the scanning microscope applications such as is employed in the PACT system. The reason for this is that this program concludes the basic implementation and analysis of the pattern recognition technology initiated under the previous program, Contract DAAA 15-72-C-0375. Further work in this area, therefore, initially should concentrate on refining of the overall system by means of hardware refinement, testing and subsequent miniaturization. Analytical support for this evolutionary development and refinement of the hardware also would be provided.

TABLE 5-2 COUNT RATES FOR VARIOUS AGENTS

Agent	Large Counts C_L	Small Counts C_s	Correlator Counts Detected	Sensitivity (Relative Rate of Total Counts Detected)
Dugway VEE	2841	7868	506	4.7
Dugway Sm	123	32948	11826	35.7
Dugway Q	233	4269	1271	28.2
Dugway Pt	154	13369	789	5.8
Edgewood Dry Carbon without stain	1	25	0	0
Wet Carbon with stain	4	1151	67	5.8
Wet Sm	48	6582	1744	26.3
Wet Yeast	876	1548	66	2.7
Wet Mold Spore	4469	8389	2795	21.7
Wet Killed Pt	20	3601	123	3.4
Dry Bg	416	19636	10834	54.0
Wet Whole Egg	48	7038	1800	25.4
Wet Bg	46	9362	3275	34.8
Dry Select Egg	1405	1330	587	21.5
Dry Sm	72	8746	4479	50.8
Edgewood Background (0800 hrs.)	611	1973	221	8.6
Wet Select Egg	444	4262	452	9.6
Edgewood Background (1130 hrs.)	677	2522	231	7.2
Dugway Background	320	8978	1082	11.6
Dugway Background with Sm cloud	390	16422	2963	17.6

5.3.1 Analysis

The analysis phase of this program would be heavily oriented towards support of future hardware evolution and refinement, but would not necessarily be restricted to these areas. The analysis would include the following tasks:

- Analytical support for hardware development and testing in Section 5.3.2 below, providing recommendations and anticipated performance. Analytical support and recommendations also would be furnished to the Army to provide needed assistance in field testing and evaluation as well as in other applications of the PACT system.

- Installation and operation of a GFE Mark VI PACT system at the contractor's site to provide test data. This would permit the use of background/agent combinations under a wide variety of backgrounds (due to weather variation) and permit agent signals of varying densities to be monitored in the presence of these backgrounds. The basic function, therefore, would be to analyze and check out the operation of the alarm logic. While the existing tape library is fairly complete, such a controllable source would be desirable for this purpose.

- Analysis of additions and/or changes in the existing alarm logic concept. This would include a survey of different approaches to the alarm logic functions (i.e. which data channels are being monitored and how) and methods of interconnecting the different functions in the logic which produces the ultimate alarm. This task would provide a final output in the form of a refined alarm logic system which would be built under the hardware phase of this program.

5.3.2 Hardware Development

The purpose of future hardware development involves all of the existing subsystems implemented previously. This hardware development can be performed subsequent to the above analysis and tasks as a follow-on program. It includes, but is not necessarily limited, to the following objectives:

- Design, fabrication and testing of an Advanced Mold Spore Detector utilizing the three-window concept and associated logic as discussed in Section 5.2.5. Its design can draw heavily from previous work.

- Upgrading of performance. This can be accomplished through such possible means as minor circuit refinements which improve such parameters as stability and speed.

- Size reduction of electronic subassembly through the following means:

    1. Circuit simplication through elimination of redundant and superfluous components and circuits and through the use of alternate techniques to achieve the same function.

    2. Repackaging of subassemblies making extensive use of hybrid technology, new ICs and microprocessors, as well as different mounting and interconnecting techniques where a size reduction is realizable.

- Cost reduction through the judicious application of the means just described.

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